HORMONAL, CARDIOVASCULAR AND HEARING RESPONSES IN MEN DUE TO COMBINED EXPOSURES TO NOISE, WHOLE BODY VIBRATIONS AND DIFFERENT TEMPERATURES

Manninen, O.

The Academy of Finland, c/o Department of Public Health, Medical Faculty, University of Tampere, P.O. Box 607, SF-33101 Tampere, Finland

ABSTRACT

The purpose of this study was to examine changes in the secretion of catecholamines in urine, certain cardiovascular and haemodynamic activities, and temporary hearing thresholds found in young people when they were exposed to mere stable noise, sinusoidal 5 Hz whole body vibration along the Z-axis (rms acceleration 2.12 m/s²), stochastic whole body vibration with the frequency range 2.8 - 11.2 Hz along the Z-axis (rms acceleration 2.12 m/s²), a dry bulb temperature of 20°C, a dry bulb temperature of 35°C or simultaneous combinations of the noise, vibrations and temperatures listed above. The number of exposure combinations studied was 12. The study was conducted in a special exposure chamber as a factorial experiment. The total duration of one personal test was six hours. The results showed that there was a certain relation between hormonal, cardiovascular and auditory changes and the combined exposures the persons were subjected to.

Key words: cardiovascular activity, changes in hearing, complex exposures, urinary catecholamines

INTRODUCTION

Earlier studies have shown that, for instance, intense noise, vibration or varying temperatures may rapidly deteriorate the hearing ability, increase blood pressure or otherwise adversely affect the cardiovascular and haemodynamic functions of the human body. These changes are however not very straightforward and caused by one single environmental factor; rather, they appear most clearly after an exposure to a combination of various environmental factors. Unfortunately our knowledge of the simultaneous and often very complex combined effects of environmental factors is rather
scanty and limited. For this reason we cannot with surety present any general conclusions about, for example, the mechanisms of the development of complex environment-induced diseases.

Therefore, the very purpose of this study was to obtain additional knowledge about changes in hearing and cardiovascular and hormonal functions when subjects are exposed to noise or vibration alone or noise and vibration simultaneously at two different temperatures. One further objective was to find possible connections between hearing and cardiovascular and hormonal functions in these complex exposures that differed from earlier exposures in their rather long duration and in their thermal conditions.

This study is part of a years-lasting and extensive research project concerned with the combined effects of environmental factors on the functions of human body in both laboratory conditions and in the field.

MATERIAL AND METHODS

This report discusses functional changes in the body on the basis of the results of measurements made in the morning after an exposure of about 2 hours (third exposure measurement) and in the afternoon after an exposure of about 4 hours (sixth exposure measurement). The exposures were repeated in the morning and in the afternoon in precisely the same way and following the same schedule. Only at noon there was a pause for one hour which the subjects spent resting on a bed.

The experiment was carried out by means of a special exposure chamber. The chamber and the measuring equipments were developed during the methodological working period of the research programme (see Manninen 1983a,b; 1986a).
Experimental Design. Interactions between environmental factors were studied through a three-dimensional variance analytic model (Winer 1962); a four-dimensional model with time as the fourth dimension would be too far fetched at the time being, and the interactions produced would be too difficult to understand. Therefore, the analysis of morning and afternoon samples was performed separately. Tests were run as a 2-2-3 type factorial experiment; thus the number of exposure combinations investigated amounted to 12. There were five subjects in each combination (n=60). Each subject was treated only once.

Subjects. Sixty health, young male university students, none of whom had previously been subjects in exposure experiments, participated voluntarily in the investigation. The subjects' activity, waking hours, sleep, eating, use of medicine and alcohol was monitored by means of written instructions and diaries kept by the subjects. The subjects were paid an hourly fee for the time spent on the experiments.

Exposure arrangements. During the test, subjects sat in a vibration chair. The dry bulb temperature of the exposure chamber during the test was either 1) 20°C or 2) 35°C. The speed of air flow, relative humidity and illumination of general lighting was kept constant in all experiments. The noise categories were 1) no noise, 2) broad-band A-filtered stable noise at an intensity of 90 dB. The categories of vertical (along z-axis) whole body vibration were 1) no vibration, 2) sinusoidal 5 Hz vibration, 3) stochastic broadband vibration over the frequency range 2.8 - 11.2 Hz. The acceleration (rms) of both sinusoidal and stochastic vibration was 2.12 m/s². During the exposure tests, the subjects worked with a choice-reaction device using the fingers of the right hand in their own pace. The task was very easy. Each personal test lasted for approximately six hours. It consisted of rest sessions and sequential exposure periods lasting 16 minutes each. Between exposure periods there was a pause of four
minutes. During that time the subject rested or the necessary measurements including audiometric and cardiovascular recordings took place.

**Audiometric measurements (TTS).** The hearing threshold values were determined with a pure tone audiometer (type Interacoustics Diagnostic Audiometer AD17) using the ascending technique. The hearing thresholds of both ears were measured in the same way each time at frequencies of 4000 Hz and 6000 Hz, and exactly 2 min after the cessation of the exposure (i.e. TTS₂; see also Manninen 1983a; Manninen and Ekblom 1984).

**Determination of heart rate (HR).** During the experiment, the heart rate functioning of the subjects was monitored continuously with a two-channel memory cardioscope (type Olli 332). The heart rate (beats/min) was determined manually from an ECG band during each measurement, exactly 10 s after the end of the pre-exposure, exposure and resting periods (see also Manninen 1984, 1985, 1986a).

**Blood pressure measurements (DBP, SBP).** Diastolic blood pressure and systolic blood pressure were measured with a sphygmomanometer (type Speidel & Keller KG electronic Tono-print). Blood pressure was measured 40 s after the end of the pre-exposure, exposure and resting periods (see also Manninen 1986a).

**Haemodynamic index (HDI).** Cardiovascular activity and oxygen consumption of the myocardium of the subjects were characterized by calculating a haemodynamic index score (e.g. Robinson 1967). To make the index the product of the heart rate value and the systolic blood pressure value was divided by one thousand (see also Manninen 1985, 1986a,b).

**Determination of catecholamines in urine (A, NA, DOPA).** Adrenaline (A), noradrenaline (NA) and dopamine (DOPA) concentrations in urine are relatively low, from a few micrograms per liter to a few hundred, which imposes special requirements on their determination. Urine samples were col-
lected after the exposure and both in the morning and in the afternoon. Catecholamines had to be separated from urine before actual qualitative analysis by a high-performance liquid chromatograph. The high performance liquid chromatograph was composed of a Perkin-Elmer LS series pump (type LS-10) and fluorescence detector (type LS-4) whose excitation wavelength was 281 nm and emission wavelength 315 nm. Quantitation was done with an integrator (type HP 3390A), which calculated the catecholamine concentrations by the external standard method. The actual separation took place in columns packed with a 5 μ absorbent (type Spherisorb ODS 2; 250 mm x 4.6 mm). The washing solution was a 0.1M sodium fosfate buffer to which 121 mg heptasulfonic acid and 60 mg Na₂EDTA was added per liter. Concentrations of urinary catecholamines have been expressed as excretion rates of adrenaline, noradrenaline and dopamine (ng/min).

Statistical Treatment. The results are discussed on the basis of overall means calculated for the entire material and standard errors of means in various classes of noise, vibration and temperature. The statistical testing of differences of means is carried out by the Student's t-tests for differences of unpaired means. Main and combined effects are tested by a variance analysis. Association between variables are characterized by multiple correlation coefficients (R) and Pearson's product moment correlation coefficients (r)

Except the hormone contents, all primary results have been corrected by the results of the second pre-exposure, control measurements. The subjects acted as their own controls.

RESULTS

Overall Means

The main effects of noise, vibration and temperature are presented in Figures 1-30. The diagrams have been drawn over the whole material on the basis of arithmetic means and
standard errors of means by classes of noise, vibration and temperature; there are separate diagrams for the morning and for the afternoon. The values characterize functional changes in the body observed in the morning or in the afternoon in measurements made after the last period of exposure.

In the morning the overall means of the TTS₂ values after the first exposure period were higher at 35°C than at 20°C. The difference diminished during the exposure, and after the third successive period of exposure the difference in the means of the TTS₂ values between temperature classes was one and a half decibels (Figure 1). The effect of temperature on the TTS₂ values was not as evident at 6 kHz as at 4 kHz (Figure 2).

The highest rise in temporary hearing threshold due to noise was found for the first 16-min period of exposure. During the morning a noise exposure increased the TTS₂ values measured after the third successive period of exposure in average by 2 dB. The highest TTS₂ values were measured in the afternoon after the last exposure period, albeit these values were only 3 dB higher than the values measured after the first period of exposure in the morning (Figure 3). The values of hearing threshold at 6 kHz were rather similar to those at 4 kHz (Figure 4).

A vibration exposure also affected the TTS₂ values. A sinusoidal 5 Hz vibration increased the TTS₂ values both at 4 kHz and 6 kHz slightly more than stochastic wide-band vibration (Figure 5 and 6). The differences between vibration classes were greatest in the afternoon after the last period of exposure.

The overall means of the SBP values were markedly lower at 35°C than at 20°C. At 35°C they decreased and at 20°C they increased during exposure. The greatest differences were found in the afternoon after the last exposure (Figure 7). The overall means of the DBP values were also higher at 20°C than at 35°C. The highest means of the DBP values were found in
Fig.1-6. Overall means (x) of the TTS₂ values and standard errors of means (SEM) at 4 kHz and 6 kHz at different temperature, noise and vibration classes in the morning and in the afternoon. Values are calculated on the basis of hearing thresholds of both ears.
the afternoon after the last exposure (Figure 8). The overall means of HR values were slightly higher at 35°C than at 20°C both in the morning and in the afternoon (Figure 9). The overall means of haemodynamic index were somewhat lower at 35°C than at 20°C both in the morning and in the afternoon, but they were nevertheless higher than before the exposure (Figure 10).

**Fig. 7-10.** Overall means (\(\bar{x}\)) of the SBP, DBP, HR and HDI values and standard errors of means (SEM) at different classes of temperature in the morning and in the afternoon.
The overall means of the urine secretion rate were markedly higher at 20°C than at 30°C both in the morning and in the afternoon (Figure 11). It should also be noted here that the urine secretion rate increased during the afternoon from the morning values at 20°C, while at 35°C the secretion rate remained virtually constant. During

Fig. 11-14. Overall means (x) of the urine, adrenaline, noradrenaline and dopamine secretion and standard errors of means (SEM) at different classes of temperature in the morning and in the afternoon.
both morning and afternoon the adrenaline secretion rate at 20°C was higher after various combined exposures at 35°C than after exposures at 20°C (Figure 12). The overall means of the noradrenaline secretion rates in the morning were higher at 20°C than at 35°C (Figure 13). The overall means of dopamine secretion rates, in turn, were in the afternoon markedly higher at 35°C than at 20°C (Figure 14).

The overall means of the SBP values in the afternoon were highest under the effect of a 90 dBA noise (Figure 15). By contrast, the means of the DBP values decreased slightly due to this type of exposure. The differences between classes were clearest after the last exposure period before noon (Figure 16). In the afternoon, then, no differences of

![Figures 15-18](image-url)

**Fig.15-18.** Overall means ($\bar{x}$) of the SBP, DBP, HR and HDI values and standard errors of means (SEM) at different classes of noise in the morning and in the afternoon.
such magnitude could be observed. Noise increased average heart rate slightly more during the morning than afternoon (Figure 17). Combinations containing a 90 dBA noise increased the HDI values more than those with no noise (Figure 18).

Noise alone did not affect the urine secretion rate (Figure 19). By contrast, exposure combinations containing a 90 dBA noise curbed the noradrenaline secretion (Figure 20) but increased the secretion of noradrenaline (Figure 21) and to some extend also secretion of dopamine (Figure 22) in urine, in particular during the afternoon.

Fig. 19-22. Overall means ($\bar{x}$) of the urine, adrenaline, noradrenaline and dopamine secretion and standard errors of means (SEM) at different classes of noise in the morning and in the afternoon.
During morning and afternoon the overall means of the SBP values decreased most due to stochastic vibration (Figure 23). A point of special interest is that during the last exposure in the afternoon a sinusoidal 5 Hz vibration increased and stochastic vibration decreased the means of the SBP values. As in the case of the SBP values, sinusoidal vibration also increased the DBP values most in the afternoon during the last exposure (Figure 24). On the other hand, exposure combinations containing stochastic vibration increased the HR values both in the morning and in the afternoon less than exposure combinations containing only sinusoidal vibration or no vibration (Figure 25). Likewise, stochastic vibration increased the HDI values less than

Fig. 23-26. Overall means (x) of the SBP, DBP, HR and HDI values and standard errors of means (SEM) at different classes of vibration in the morning and in the afternoon.
sinusoidal vibration or exposure combinations with no vibration (Figure 26). The highest index values were found after the last exposure in the afternoon when the exposure combinations had contained sinusoidal vibration.

Sinusoidal and stochastic vibration did not affect the urine secretion rate (Figure 27). On the other hand, particularly during the morning the adrenaline secretion rate was

Fig. 27-30. Overall means (X) of the urine, adrenaline, noradrenaline and dopamine secretion and standard errors of means (SEM) at different classes of vibration in the morning and in the afternoon.
markedly higher after a stochastic vibration exposure than after exposure to combinations containing sinusoidal vibration or no vibration (Figure 28). The overall means of the noradrenaline secretion rate, in turn, were markedly lower after an exposure to sinusoidal vibration during morning than after an exposure to combinations containing no vibration (Figure 29). The overall means of dopamine secretion rate were markedly high in the afternoon after an exposure to sinusoidal or stochastic vibration (Figure 30).

Single and Combined Effects

The single and combined effects of noise, vibration and temperature were studied in more detail with the aid of variance analyses, which indicated that in the morning after the last successive period of exposure (i.e., a 6-week measurement) noise explained the main part of the variation in the TTS₂ values at 4 kHz (F value = 393.6; df = 1,108; p < 0.001). In the evaluation after the last measurement in the afternoon the shares of different factors in explaining variation changed: the single effect of noise was statistically very significant (F value = 436.8; df = 1,108; p < 0.001), the single effect of vibration was significant (F value = 3.8; df = 2,108; p < 0.05), and the combined effect of noise and temperature was significant (F value = 5.4; df = 1,108; p < 0.05). Noise and vibration, in turn, explained variation in the TTS₂ values at 6 kHz both in the morning and in the afternoon. The single effect of noise was statistically very significant both in the morning (F value = 306.7; df = 1,108; p < 0.001) and in the afternoon (F value = 254.6; df = 1,108; p < 0.001). Correspondingly, the single effects of vibration were statistically very significant after the last exposure period, both in the morning (F value = 3.8; df = 2,108; p < 0.05) and in the afternoon (F value = 3.0; df = 2,108; p < 0.05).
The squares of multiple correlation factors ($R^2 \times 100$) indicated that noise and vibration together explained both during the morning and the afternoon 86% of the variation in the TTS$_2$ values at 4 kHz. Correspondingly, noise and vibration explained 79% of the variation in the TTS$_2$ values in the morning and 72% in the afternoon.

Variation in the SBP values during the last exposure in the morning was affected most by temperature ($F$ value = 48.0; $df = 1,48$; $p < 0.001$), by vibration ($F$ value = 8.9; $df = 2,48$; $p < 0.001$) and temperature and vibration jointly ($F$ value = 3.0; $df = 2,48$; $p < 0.05$). In the afternoon the explanatory shares changed: besides the single effect of temperature ($F$ value = 11.4; $df = 1,48$; $p < 0.001$), the single effect of vibration ($F$ value = 10.4; $df = 2,48$; $p < 0.001$), the combined effect of temperature and vibration ($F$ value = 4.2; $df = 2,48$; $p < 0.05$), noise, too, had a statistically significant single effect at the level of 10% ($F$ value = 2.7; $df = 1,48$).

Temperature explained a statistically significant degree variation in the DBP values both in the morning ($F$ value = 6.7; $df = 1,48$; $p < 0.05$) and in the afternoon ($F$ value = 3.9; $df = 1,48$; $p < 0.05$). In the afternoon noise and vibration had a statistically significant combined effect during the last exposure period ($F$ value = 5.0; $df = 2,48$; $p < 0.01$).

Out of the factors used in the variance analysis model vibration had the highest explanatory power for the variation in the HR values both in the morning ($F$ value = 5.0; $df = 2,48$; $p < 0.01$) and in the afternoon ($F$ value = 2.5; $df = 2,48$; $p < 0.10$). Vibration and temperature had a statistically significant combined effect on variation in the HR values both in the morning ($F$ value = 3.3; $df = 2,48$; $p < 0.05$) and in the afternoon ($F$ value = 3.3; $df = 2,48$; $p < 0.05$).
Variation in the HDI values in the morning was affected significantly by vibration (F value = 3.5; df = 2, 48; p < 0.05), by temperature, (F value = 3.1; df = 1, 48; p < 0.10) and by vibration and temperature together (F value = 4.5; df = 2, 48; p < 0.01). In the afternoon variation in the HDI values was best explained by vibration alone (F value = 4.0; df = 2, 48; p < 0.05) and vibration and temperature together (F value = 5.1; df = 2, 48; p < 0.01).

Variation in the urine secretion rates was best explained by temperature variation. Temperature had a significant single effect on the urine secretion rates both in the morning (F value = 19.7; df = 1, 48; p < 0.001) and in the afternoon (F value = 113.3; df = 1, 48; p < 0.001). In addition, temperature and vibration had a statistically significant combined effect on variation in the urine secretion rate in the morning (F value = 2.8; df = 2, 48; p < 0.10). Temperature, noise and vibration together explained to a statistically significant degree variation in the urine secretion rate both in the morning (F value = 5.1; df = 4, 48; p < 0.005) and in the afternoon (F value = 27.5; df = 4, 48; p < 0.001).

In the morning mere temperature explained variation in the adrenaline secretion rate at the level of 1% (F value = 7.2; df = 1, 48) and mere vibration gave some indication about it (F value = 2.4; df = 2, 48). In the afternoon temperature had a significant single effect at the level of 1% (F value = 11.3; df = 1, 48) and temperature and noise together had an indicative combined effect (F value = 3.6; df = 1, 48) on the variation in the adrenaline secretion rate. All factors together explained variation in the adrenaline secretion rate in the morning at the level of 5% (F value = 3.2; df = 4, 48) and in the afternoon at the level of 1% (F value = 3.4; df = 4, 48).

In the morning temperature and noise had a statistically significant combined effect on the variation in the dopamine secretion rate (F value = 6.3; df = 1, 48; p < 0.01). In the
afternoon all three factors had an indicative combined effect (F value = 2.1; df = 4,48) and temperature had an indicative single effect (F value = 3.7; df = 1,48) on the dopamine secretion rate.

The whole variance analysis model ($R^2 \times 100$) (noise, vibration and temperature together) explained 31% of the variation in the adrenaline secretion rate in the morning and 18% in the afternoon. As to variation in the noradrenaline secretion rate the entire model explained 17% of it in the morning and 11% in the evening. In the case of dopamine secretion the corresponding percentages were 14 (morning) and 21 (afternoon).

Means by Exposure Combinations

As a variance analysis model does not necessarily give a detailed picture of all possible interactions between temperature, noise and vibration, we calculated the means of the adrenaline, noradrenaline and dopamine secretion rates and standard errors of these means for exposure combinations on the basis of measurements made in the morning and in the afternoon (Table 1). As the table indicates, sinusoidal and stochastic vibration increased the adrenaline secretion rate particularly in the afternoon when the subjects were simultaneously exposed to a 90 dBA noise at a temperature of 20°C. Noradrenaline secretion rate, in turn, increased during an exposure to sinusoidal vibration if the subjects were simultaneously exposed to a 90 dBA noise either at 35°C or at 20°C. A low temperature (20°C) increased the noradrenaline secretion rate especially when the subjects were exposed to sinusoidal vibration. Both sinusoidal and stochastic vibration increased dopamine secretion rate in the afternoon when the subjects had besides vibration been exposed to a simultaneous 90 dBA at a temperature of 35°C.
Table 1. Arithmetic means (x) and standard errors of the means (SEM) of the adrenaline, noradrenaline and dopamine secretion rates (ng/min) determined in the morning and in the afternoon by exposure combinations (n=60).

<table>
<thead>
<tr>
<th>Vibration level</th>
<th>Dry-bulb temperature</th>
<th>20°C</th>
<th>20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No noise level</td>
<td>Noise of 90 dB(A)</td>
<td>No noise</td>
</tr>
<tr>
<td></td>
<td>x±SEM</td>
<td>x±SEM</td>
<td>x±SEM</td>
</tr>
<tr>
<td>No vibration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>an</td>
<td>17±5</td>
<td>14±4</td>
<td>11±3</td>
</tr>
<tr>
<td>pm</td>
<td>27±7</td>
<td>28±3</td>
<td>8±1</td>
</tr>
<tr>
<td></td>
<td>32±5</td>
<td>34±3</td>
<td>5±1</td>
</tr>
<tr>
<td>Vibration frequency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of 2 Hz (2.12 m/s²)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>an</td>
<td>12±4</td>
<td>12±3</td>
<td>8±1</td>
</tr>
<tr>
<td>pm</td>
<td>24±11</td>
<td>24±11</td>
<td>4±1</td>
</tr>
<tr>
<td></td>
<td>26±7</td>
<td>26±7</td>
<td>4±1</td>
</tr>
<tr>
<td>of 2.8-11.2 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2.12 m/s²)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>an</td>
<td>28±8</td>
<td>15±3</td>
<td>10±2</td>
</tr>
<tr>
<td>pm</td>
<td>46±8</td>
<td>52±16</td>
<td>4±7</td>
</tr>
<tr>
<td></td>
<td>32±14</td>
<td>32±14</td>
<td>4±7</td>
</tr>
</tbody>
</table>

a1 - adrenaline, 2 - noradrenaline, 3 - dopamine
*p<0.05

Correlation Coefficients by Exposure Combinations

To depict association in more detail product moment correlation coefficients between the TTS₂ values and hormone contents were calculated for each exposure combination. Positive correlation coefficients were found in particular for simultaneous exposures to sinusoidal vibration and noise at 20°C or to stochastic vibration and noise at 35°C. The coefficients were often higher in the afternoon than in the morning.
The correlation of the TTS₂ at 4 kHz values with the adrenaline secretion rate was 0.40 in the afternoon; with dopamine secretion rate it was 0.56 (p < 0.05; df = 10) in the morning and 0.65 in the afternoon (p < 0.10; df = 10). The TTS₂ values at 6 kHz showed a correlation of 0.25 with the adrenaline secretion rate in the morning and 0.65 in the afternoon (p < 0.05; df = 10) and 0.13 with dopamine secretion rate in the afternoon, while the correlation coefficients between the TTS₂ values and the noradrenaline secretion rates were negative (r = -0.40 - -0.48).

When the subjects were exposed to stochastic vibration and noise at 20°C, in particular the TTS₂ values at 6 kHz correlated positively with hormone contents both in the morning and in the afternoon; the TTS₂ values correlated 0.56 with the adrenaline secretion rate in the morning (p < 0.05; df = 10) and 0.02 in the afternoon; correlation with the noradrenaline secretion rate was 0.22 in the morning and 0.23 in the afternoon; correlation with dopamine secretion rate was 0.17 in the morning and 0.55 in the afternoon (p < 0.10; df = 10).

In the afternoon the TTS₂ values at 4 kHz also correlated positively with hormone contents when the subjects were exposed to stochastic vibration and noise at 35°C. The coefficient between the TTS₂ values and the adrenaline secretion rate was 0.19, the coefficient between the TTS₂ values and the noradrenaline secretion rate was 0.16 and the coefficient between the TTS₂ values and dopamine secretion rate was 0.50 (p < 0.10; df = 10).

When the results of successive measurements were pooled into a single material in each cell (n=5 x 10), we could observe that there was a rather interesting correlation between variables depicting cardiovascular activities and changes in temporary hearing thresholds. Out of the cardiovascular variables studied in particular the HDI values correlated positively with the TTS₂ values. The correlation
coefficients were high especially when the subjects were exposed to mere 90 dBA noise either at 20°C (r = 0.28 - 0.46) or at 35°C (r = 0.15 - 0.62) or to simultaneous stochastic vibration and noise either at 20°C (r = 0.50 - 0.51) or at 35°C (r = 0.32 - 0.51; df = 50; p < 0.01 - 0.001).

DISCUSSION

As a whole the results showed that the temporary hearing threshold rises significantly much when the subjects, while doing mentally and physically light work, are exposed repeatedly to vibration simultaneously with intense noise. Temperature, too, had a bearing on how TTS_2 values rose during the exposure. However, if we are to gain better understanding of the phenomenon and direct further studies effectively, the most essential point was perhaps that the secretion rates of catecholamines in urine and the values of the haemodynamic index were high and correlated positively with TTS_2 values especially after a simultaneous exposure to noise and vibration: the greater increase in HDI values and in adrenaline and dopamine excretion, due to simultaneous noise and vibration, the greater the increase in TTS_2 values. These results lend support to my earlier results.

However, the results should be viewed carefully and with some reservations, since the variance analysis model used does not necessarily give a detailed picture of the special features of hormone secretion and combinations of factors affecting it. As we noted, the most significant and also most fruitful differences were found in the t-tests. As regards statistical testing in general, the most useful strategy is one where both a multidimensional variance analysis and a t-test are used in parallel for analyzing the same material.

In modern built environments many physical and chemical environmental factors form an integral whole whose components cannot without reservations be detached for a separate
analysis or omitted. For instance, the effects of single environmental factors may considerably differ from the effects that certain combinations of these factors may have on the human body. I have presented the above results as examples of the complex character of the interactions between single factors.

It is particularly interesting to note that cardiovascular and haemodynamic as well as hormonal changes are consistently correlated to changes in temporary threshold shifts of hearing in complex exposures. The degree of correlation is affected not only by the frequency range and bandwidth of noise but also by such factors as whether the subject is simultaneously exposed to a whole body vibration, the temperature at which exposures to noise and vibration take place, and the physical and mental strain of the subjects during simultaneous noise, vibration and temperature exposures. We know from previous experience that the product of heart rate and systolic blood pressure correlates rather strongly with deterioration of the contraction of heart muscle and arrhythmia. It has also been observed that persons suffering from coronary disease feel pain in the chest particularly when their oxygen consumption exceeds a certain critical index value due to physical or mental strain. The results presented in this paper, in turn, indicate that noise, vibration and temperature, too, increase this index value and accelerates oxygen consumption.

Moreover, the newest observations (Manninen 1986a,b) show that the duration of the exposure period and the character of vibration have their special effects on the changes in hearing threshold and in haemodynamic and cardiovascular functions. As with noise, the frequency and bandwidth of vibration also has a hearing on the combined effects of, for instance, noise and vibration. In other words, the ultimate result is essentially dependent on what factors and combinations of these
factors are active from the first minute of exposure to one hour. An exposure of one hour can be considered a sort of boundary value, after which changes in the body start to happen periodically; i.e., depending on the criterium variable, the intensity of changes observed may increase or decrease periodically from its initial level with the duration of the exposure. This, in turn, means that to reach higher reliability in observations we have to concentrate more on the effects of complex exposure combinations and longer exposure times.

REFERENCES


Manninen O (1983b) Simultaneous effects of sinusoidal whole body vibration and broadband noise on TTS₂'s and R-waves amplitude in men at two different dry bulb temperatures. Int Arch Occup Environ Health 51:289-297


Manninen O (1985) Cardiovascular changes and hearing threshold shifts in men under complex exposures to noise, whole body vibrations, temperatures and competition-type psychic load. Arch Occup Environ Health 56:251-274

Manninen O (1986a) Bioreponses in men after repeated exposures to single and simultaneous sinusoidal or stochastic whole body vibrations of varying bandwidths and noise. Int Arch Occup Environ Health 57:267-295