The Meaning of Complex Exposures Regarding Vibration Studies

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Vibration can be considered as one of the most common physical environmental factors. Vibration, however, does not usually occur alone in an environment; other environmental factors or factors related to work and traffic situations are almost always connected with it. The study of the combined effects of vibration and various other environmental factors is therefore justified. With a view to achievement of progress in occupational and environmental health it is important to study, how the own experiences and estimates of the exposed persons reflect the properties of noise and vibration. The significance of a study like this is accentuated by the fact that our knowledge about the correspondence of the evaluation results and the
characteristics of the influential factors are meager in those cases where people are simultaneously exposed to noise and vibration.

In his paper the author describes the main results from the laboratory studies whose purpose was, in fact, to improve the truthfulness of vibration studies - in the sense that in addition to sinusoidal whole body vibration the subjects were exposed to different kinds of stochastic whole body vibrations under different noises, temperatures and workloads. It was expressly examined, how stressful the subjects considered single or complex exposure conditions to be during the experiment.

Material and methods

The experiments were carried out in a special exposure chamber (see details Manninen 1983, 1984a). The subjects were voluntary, young, fit, healthy and previously non-exposed male students. One experiment (n=108) was carried out as factorial experiment, the other as an experiment based on randomized block design (n=10).

During the experiments the subjects sat in a vibration chair (i.e. whole body vibration along the Z-axis). In the factorial experiment the classes of vibration were 1) no vibration, 2) sinusoidal vibration, and 3) stochastic vibration. The (rms) acceleration of the two classes of vibration was standardized at 2.12 m/s$^2$. The significance of the bandwidth was evaluated with an exposure to vibration in the frequency range 2.8 to 11.2 Hz, and a sinusoidal 5 Hz frequency vibration excitation. The noise was A-weighted white noise with cutoff frequencies of 0.2 and 16.0 kHz and an intensity of 90 dB. The three noise classes and the psychic load situations included were 1) no noise, no competition, 2) noise of 90 dBA, no competition, and 3) noise of 90 dBA combined with simultaneous competition using the choice reaction apparatus. The competitor achieving the fastest reaction time with the fewest errors could win FIM2000, whereas the non-competitors were allowed to operate freely the choice reaction apparatus at the speed they considered best without any financial incentive. The dry-bulb temperature of the exposure chamber was maintained at 1) 20°C or 2) 30°C. The illumination of the general lighting was 300 lux throughout the experimental session. In the experiment based on randomized block design the classes of stable broadband noise were 1) no noise, 2) noise of 85 dBA, and 3) noise of 95 dBA. The classes of whole body vibration (Z-axis) were 1) no vibration, 2) sinusoidal vibration of a frequency of 5 Hz (rms acceleration 2.12 m/s$^2$), 3) sinusoidal vibration of 5 Hz (rms acceleration 2.44 m/s$^2$) and 4) stochastic vibration of a frequency of 1.4-11.2 Hz (rms acceleration 2.12 m/s$^2$). The dry-bulb temperature was 20°C, and the illumination level of the general lighting was 300 lux during the exposure periods.

Each subject was exposed consecutively three times during factorial experiment and two times during the block design experiment for 16 minutes. The stressfulness ratings were carried out after the exposure periods on a five-class rating scale.

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The ratings were made by using the following instructions and scale: "Next you are asked to rate the stressfulness of the preceding exposure period on the basis of your personal sensation. You need not think what the different meters might show, only state, using the following scale of rating, how you feel yourself. Scale of rating 1 = very stressful, 2 = stressful, 3 = rather stressful, 4 = slightly stressful, 5 = very little stressful." In making his ratings the subject related his experience with control period experience. Each subject was thus "zeroed", calibrated with the aid of control period conditions.

The statistical significance of the differences between unpaired means was determined using two-tailed Student's t-tests. The statistical significance of the main effects of and interactions between various factors was examined with the aid of three-way variance analyses.

Results

The most essential results have been presented in Table 1 and in Figure 1. Analysis of the means of scores of stressfulness ratings (Table 1) suggests that the increase in stressfulness due to noise and related competition type psychic stress is higher at a temperature of 30°C than at 20°C. Simultaneous exposure to sinusoidal vibration and noise was estimated among the subjects as less stressful than exposure to mere sinusoidal vibration, or a combination of sinusoidal vibration, noise and competition. Estimates of stressfulness of exposure to stochastic vibration differed from others mainly in that stochastic vibration by itself was estimated as less stressful than sinusoidal vibration — especially when the ambient temperature exceeded 30°C. Competition type stress also seemed to relieve stress caused by noise and stochastic vibration. After the first exposure period, vibration by itself (F-value 6.6; df = 2.90; p<0.002) and high temperature (F-value 3.7; df = 1.90; p<0.05) had a single effect of statistical significance; together, vibration and heat (F-value 5.1; df = 4.90; p<0.008) and, on the other hand, vibration and noise (F-value 2.8; df = 4.90; p<0.03) had a statistically significant combined effect. As compared to the values obtained from the first exposure, there were virtually no changes in the single and combined effects of the factors after the second and the third exposure period.
Figure 1 shows the results of the stressfulness ratings according to the noise and vibration combinations. As indicated by the results, the stressfulness was rated the smallest, when the subjects had not been exposed to any vibration or noise.

The basic noise level in the exposure chamber was about 50 dBA. It was caused by either the operating of the air conditioning equipment, or during exposure to vibration alone, by the movements of the vibrating chair and the operating of the servo valves. When the intensity of noise in the exposure chamber was increased from 50 dBA to 85 dBA with the aid of loudspeakers, the subjects considered that, compared with the preceding test, the test situation was significantly more stressful \((t = 4.58; \text{df} = 9; p<0.001)\). When the intensity of noise was further increased from 85 dBA to 95 dBA, the stressfulness increased almost linearly.

Out of the vibrations, which were examined, stochastic broadband (frequency range 1.4-11.2 Hz) was rated as the least stressful but significantly more stressful \((t = 4.74; \text{df} = 9; p<0.001)\) than the situation in which the subjects were not exposed to vibration or noise at all. The second most stressful was vibration of 5 Hz with an acceleration of 2.12 m/s². Mere vibration, again, was rated as the most stressful in cases where the frequency of the vibration was 5 Hz and acceleration 2.44 m/s². An increase in acceleration thus increased the stressfulness of vibration essentially \((t = 2.71; \text{df} = 9; p<0.05)\).

As a rule, stressfulness was rated higher, when the subjects were simultaneously exposed to vibration and noise. In the case of all of the noise and vibration combinations stressfulness increased more or less in the same way, expressly, when the intensity of noise in the noise and vibration combinations increased from 85 dBA to 95 dBA. Compared with exposure to vibration alone, stressfulness increased most, when the subjects were simultaneously exposed to noise of 85 dBA and stochastic broadband vibration \((t = 6.74; \text{df} = 9; p<0.001)\).

**Discussion**

The results showed that the stress experiences of the subjects increased systematically, when they were instead of exposures to vibration or noise alone exposed to a combination of noise and vibration. In all, the results would seem to indicate that in order to avoid underestimation of the harmful effects, the exposure norms and recommendations, among others, should be amended so that the potential combined effects of noise, vibration, temperature and nature of work would be taken into consideration to a greater extent than before.
These findings, to which I have wanted to refer briefly, have significance in practice, because in general in rail and wheel vehicles vibration energy primarily concentrates on an area where the frequencies range from about 2 to 15 Hz. This frequency area is almost the same as the frequency area used in this experiment for broadband vibration. The results are all the more important, if we remember that in practical exposure situations the prevailing noise is mostly broadband, i.e. includes very many frequencies.

Until today there has been little research available pertaining to the simultaneous effects of similar and dissimilar environmental factors. Recording and measuring of people's own sensations and feelings is an economic and quick way to assess, for example, environmental stress (Manninen 1984b). Therefore, in connection with research projects dealing with total and complex exposure, attention should be paid not only to the physiological-biochemical changes in the organism, but also, more than before, to the study of the contents and validity of people's own assessments and feelings.

Acknowledgements

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References


Manninen O (1984a) Hearing threshold and heart rate in men after repeated exposure to dynamic muscle work, sinusoidal vs stochastic whole body vibration and stable broadband noise. Int Arch Occup Environ Health 54:19-32

Table 1. The arithmetic means (X) and standard errors of means (SEM) of the scores of the subjective stressfulness ratings according to exposure combinations and consecutive exposures (n=108).

<table>
<thead>
<tr>
<th>Vibration level</th>
<th>Dry-bulb temperature</th>
<th>Noise level</th>
<th>No noise</th>
<th>Noise of 90 dB(A) and competition</th>
<th>No noise</th>
<th>Noise of 90 dB(A) and competition</th>
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</thead>
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<tr>
<td></td>
<td>30 °C</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>No noise</td>
<td>4.7 ± 0.2</td>
<td>4.1 ± 0.2</td>
<td>4.0 ± 0.2</td>
<td>4.7 ± 0.2</td>
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<tr>
<td></td>
<td></td>
<td>2</td>
<td>4.7 ± 0.2</td>
<td>3.5 ± 0.4</td>
<td>3.5 ± 0.6</td>
<td>4.7 ± 0.2</td>
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<td></td>
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<td>3</td>
<td>4.5 ± 0.2</td>
<td>3.3 ± 0.5</td>
<td>3.3 ± 0.7</td>
<td>4.3 ± 0.2</td>
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<tr>
<td></td>
<td></td>
<td>4</td>
<td>4.7 ± 0.2</td>
<td>4.8 ± 0.2</td>
<td>5.0 ± 0.0</td>
<td>4.8 ± 0.2</td>
</tr>
<tr>
<td>Vibration frequency</td>
<td>5 Hz (2.12 m/s²)</td>
<td>1</td>
<td>3.0 ± 0.3</td>
<td>4.2 ± 0.2</td>
<td>3.2 ± 0.3</td>
<td>4.2 ± 0.3</td>
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<td></td>
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<td>2</td>
<td>3.3 ± 0.3</td>
<td>4.2 ± 0.3</td>
<td>3.2 ± 0.3</td>
<td>3.7 ± 0.3</td>
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<td></td>
<td></td>
<td>3</td>
<td>3.0 ± 0.5</td>
<td>4.2 ± 0.3</td>
<td>3.0 ± 0.3</td>
<td>3.8 ± 0.3</td>
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<tr>
<td></td>
<td></td>
<td>4</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
<td>5.0 ± 0.0</td>
</tr>
<tr>
<td>Vibration frequency</td>
<td>2.8-11.2 Hz (2.12 m/s²)</td>
<td>1</td>
<td>4.8 ± 0.2</td>
<td>3.7 ± 0.3</td>
<td>4.0 ± 0.3</td>
<td>4.0 ± 0.3</td>
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<tr>
<td></td>
<td></td>
<td>2</td>
<td>5.0 ± 0.0</td>
<td>3.5 ± 0.3</td>
<td>3.8 ± 0.3</td>
<td>3.5 ± 0.4</td>
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<td></td>
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<td>3</td>
<td>4.7 ± 0.2</td>
<td>3.3 ± 0.4</td>
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<td></td>
<td></td>
<td>4</td>
<td>5.0 ± 0.0</td>
<td>4.8 ± 0.2</td>
<td>4.7 ± 0.2</td>
<td>4.7 ± 0.3</td>
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</tbody>
</table>

a1 = 1st exposure, 2 = 2nd exposure, 3 = 3rd exposure, 4 = post-exposure

Figure 1. The results of the stressfulness ratings according to noise and vibration combinations (n=10). The results depict the means of stressfulness ratings carried out after the second consecutive 16-minute exposure period (total exposure time 32 minutes).