Influence of vibration exposure on tactile and thermal perception thresholds

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Aims To establish if intermittent exposure to hand-transmitted vibration had the same effect as continuous exposure on the temporary response of finger tactile and thermal perception thresholds.

Methods Two laboratory experiments were conducted. In each, 10 healthy subjects, five males and five females, participated. The subjects’ fingers were exposed to vibration under four conditions with a combination of different periods of exposure and rest periods. The vibration frequency was 125 Hz and the frequency-weighted acceleration was 5 m/s². A measure of the tactile or thermal perception was conducted before the different exposures to vibration. Immediately after the vibration exposure, the acute effect was measured continuously for the first 75 s. This was followed by regular measures for a maximum of 30 min.

Results The results showed that combinations of vibration with different periods of exposure and rest periods significantly influenced vibrotactile perception, but not thermal perception.

Conclusions These findings suggest that intermittent exposure to hand-transmitted vibration might be more beneficial for the response of the finger vibrotactile sensation than continuous exposure. This finding is inconsistent with the evaluation methods in ISO 5349-1 for vibrotactile sensation, but accurate for thermal perception.

Key words Hand–arm; intermittency; perception; QST; thermal; threshold; vibration; vibrotactile.

Introduction

The effects of vibration exposure after work with vibrating hand-held tools have been studied since the beginning of the 20th century. Today, it is known that exposure to hand-transmitted vibration could increase the occurrence of symptoms and signs of vascular, neurological and musculoskeletal disorders of the upper extremities among vibration-exposed workers [1]. The neurological symptoms could be manifested by deterioration of finger tactile perception [2–4] and/or impaired thermal perception [3,5–7].

For evaluating the effects of vibration exposure on humans, the International Standard, ISO 5349-1 [8] is at present commonly recommended. Vibration measurements according to the standard are expressed in terms of the frequency-weighted acceleration and the exposure time. In order to facilitate comparison between different durations of exposure, the daily exposure must be expressed in terms of the energy-equivalent frequency-weighted acceleration for a period of 8 h. This procedure defines a time dependency in which the vibration magnitude may be doubled if the exposure time is reduced by a factor of four. The risk for developing vibration-related symptoms is the same for a high vibration load during a short exposure time compared to a low vibration load during a long time as long as the energy-equivalent frequency-weighted acceleration is the same [8]. However, the lack of experimental and epidemiologic support for the daily time dependency adopted in the standard has been a matter of controversy in recent years [9,10]. Moreover, ISO-5349-1 does not take into account exposure divided into shorter intervals of exposure rather than one continuous exposure. It could be argued that shorter exposure duration offers the individual worker, the opportunity to recover during rest periods [11]. Such an argument implies that one 4-h exposure during a working day is more harmful than four 1-h exposures at the same acceleration spread over the whole working day. However,
there is little or no scientific evidence that intermittent exposure to hand-transmitted vibration is less damaging than continuous exposure [12–14].

Studies have shown that acute, temporary threshold shifts of thermal and vibrotactile perception can occur due to hand vibration exposure [5,15–17]. The temporary threshold shift is defined as a different threshold value before and after the vibration exposure [18] and could be used for predicting the effects of intermittent vibration exposure [2,19].

The aim of our study was to establish if intermittent exposure to hand-transmitted vibration had the same effect as continuous exposure on the temporary response of finger tactile and thermal perception thresholds.

## Methods

Ten healthy subjects, five males and five females, with no prior history of regular use of hand-held vibrating tools in occupational or leisure activities participated. All subjects were non-smokers and reported no cardiovascular or neurological disorders in their dominant hands. The subjects provided written consent on the basis of the principles in the Declaration of Helsinki to participate in the study. The Regional Board of Ethical Vetting for medical research in Umeå, Sweden, approved the study.

Experiments were performed in a room with an ambient temperature of 22°C (±2°C) and with airflow <0.2 m/s. Subjects were asked to avoid alcohol 12 h before testing and to avoid nicotine and caffeine consumption 1 h before testing. During the experiments, the subjects were dressed in light indoor clothing and they wore hearing protection during the entire test. After an acclimatization period of 15 min, finger temperature was measured using a thermocouple attached to the distal phalanx of the examined index finger. When the fingers were at lower temperatures, the subjects used hand warmers to increase the temperature.

A computer-based system was used to measure vibrotactile thresholds (thresholds at 125 Hz) via the von Békésy method (up-and-down method) in a manner compliant with the methods in ISO 13091-1 [20]. The system consists of a laptop with a specially developed program in LabView, a DAQ-card (National Instrument 6221M) and a vibration exciter (Bruel & Kjaer 4809) with an external amplifier (Sentec PA9). Thresholds were measured on the distal phalanx of the index finger of the dominant hand. Subjects placed their finger such that the centre of the finger print whorl was situated over the centre of the probe of the applicator. The subjects were seated in a chair with a backrest in front of the instrumentation set-up and instructed to apply a downward (push) force of 0.5 N (±0.25 N) during the tests. Using a pointer instrument, the applied force could be controlled by the research leader. During the test, the subject's wrist supported the hand. Subjects were instructed to press and hold the response button down as soon as they perceived a vibration sensation and to release the response button as soon as they did not perceive the vibration.

Thermal perception was measured using instruments (Somedic) outfitted with a flat contact thermo-stimulator (a Peltier contact thermode). When measuring the perception of coldness and warmness, the volar surface of the distal phalanges of the index finger was gently applied to the probe (25 × 50 mm). The area of the index finger where the probe was applied ranged from the fingertip to the distal interphalangeal joint. During the test, the hand of the subject was supported at the wrist. The perception threshold of cold and warmth was assessed by the Marstock method [21]. The rate of the temperature change was linear and ~1°C/s. The subjects were seated in a chair in front of the instrumentation and instructed to apply a downward (push) force of 1 N during the tests. The applied force could be controlled by the examiner on a pointer instrument. The subject was instructed to press a switch whenever he or she experienced the onset of a change in the sensation of temperature (cold or warm). After a response, the temperature of the thermo-stimulator changed direction—from warmth to cold or cold to warmth. In-between measurements, the subjects continuously rested their finger on the probe without applying force.

A measure of the vibrotactile perception or the thermal perception of cold and warmth was conducted before the different exposures to vibration. After completing the pretest, the subjects were instructed to place their index, middle finger and their ring finger on a horizontal wooden platform (70 × 70 mm) mounted on a vibrator (Ling Altec Model 40). Their elbows rested at a comfortable angle on an adjustable supported platform. The exposed area of the fingers ranged from the fingertip to the second phalange. The vibration, a sinusoidal vibration at a frequency of 125 Hz, was generated by an IBM computer-based system. The chosen frequency was used because previous experimental studies have shown that this frequency induces greater changes in finger tactile perception thresholds than some lower or higher frequencies do [2,22,23]. The vibration was sent via an amplifier (Sentec PA9) to the vibrator, producing motions in the vertical direction. The subjects were instructed to apply a downward force of 5 N during the entire exposure time. Both the subjects and research leader monitored the force.

Immediately after the vibration exposure, the vibrotactile threshold or temperature threshold measurements were conducted on the exposed index finger. The acute effect was measured continuously for the first 75 s. This was followed by 30 s of measures at every minute up to 10 min. The data from the last measurement were then compared with the results from the pretest. If the deviation of the respective thresholds was >2 dB (dB relative 10−6 m/s²)
In the study of the vibrotactile perception thresholds, the subjects' mean age was 23.3 years (range 21–25), mean height 174.6 cm (range 160–183) and mean weight 70 kg (range 57–85). The mean vibrotactile thresholds (dB) for the different periods of exposures (continuous/intermittent) are illustrated in Table 1. The mean change was 20.3 dB (SD 4.9 dB). No acute influence on the vibrotactile thresholds 30 s after the exposure. The mean change was 20.3 dB (SD 4.9 dB). No acute influence on the vibrotactile thresholds 30 s after the exposure.

Table 1. The mean changes in the vibrotactile and thermal perception thresholds compared to the pretest for the different experiments (a–d)

<table>
<thead>
<tr>
<th>Time (min)</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>
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<th>10</th>
<th>15</th>
<th>20</th>
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<th>30</th>
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<tr>
<td>Con. 0.5</td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>d</td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>d</td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>d</td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Vibrotactile perception thresholds (dB)</td>
<td>21.44 (6.03)</td>
<td>22.43 (5.41)</td>
<td>19.18 (2.73)</td>
<td>17.94 (3.95)</td>
<td>19.08 (5.77)</td>
<td>20.09 (5.75)</td>
<td>16.29 (3.08)</td>
<td>14.70 (5.15)</td>
<td>6.71 (4.64)</td>
<td>7.4 (5.61)</td>
<td>7.73 (5.67)</td>
<td>8.07 (6.35)</td>
<td>6.66 (5.32)</td>
<td>7.0 (3.28)</td>
</tr>
<tr>
<td>Thermal perception thresholds (°C)</td>
<td>-0.07 (0.6)</td>
<td>-0.15 (1.17)</td>
<td>-0.30 (1.02)</td>
<td>-0.54 (1.15)</td>
<td>-0.19 (0.99)</td>
<td>-0.86 (0.85)</td>
<td>-0.90 (1.08)</td>
<td>-0.08 (0.82)</td>
<td>0.04 (0.93)</td>
<td>-0.87 (0.62)</td>
<td>-0.24 (0.68)</td>
<td>-0.24 (0.49)</td>
<td>-0.07 (0.70)</td>
<td>-0.12 (0.70)</td>
</tr>
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</table>

For the thermal perception, the changes are given in the warm and cold thresholds. The results are presented for the 30 min after the vibration exposure. The standard deviation is given in parentheses.
in Figure 1 as a function of time after the exposure. The influence on the vibrotactile thresholds was significantly different due to the different combination of exposure for the first minute \((P < 0.05)\) after the exposure. The observed significant differences were between the one with shortest (2 min) exposure periods and the two longest exposure periods (16 min \(P < 0.05\); 8 min \(P < 0.01\), respectively). For the other combinations, no significant influence was found. The exposure of vibration had a significant \((0.001 < P < 0.05)\) effect on the thresholds up to 25 min after exposure. The influence was not different due to gender.

For all experimental conditions and 30 s after exposure, the mean changes of the thresholds compared with the pre-test were found to be \(-0.27^\circ C\) (SD 0.99°C) and \(-0.70^\circ C\) (SD 0.99°C) for the warmth and cold thresholds, respectively. Figures 2 and 3 show the relationship between time of measurement and changes \(^\circ C\) in the mean warmth and cold threshold compared to the pretest for the different period of exposures, respectively. The decrease in thresholds was, however, only significant for the cold threshold \((P < 0.001)\), not the warmth. The influence on the cold threshold was significant \((P < 0.001)\) for the first minute after the pre-exposure. The combinations of the different exposure types (continuous/intermittent) had no significant influence on the thermotactile perception thresholds for the sensation of cold or warmth. Moreover, the influence on the thresholds was independent of gender.

**Discussion**

This study confirms the established consensus that exposure to hand-transmitted vibration can produce a temporary change in vibrotactile sensitivity \([25,26]\) and the measured changes of the vibrotactile perception agree with those reported earlier \([18,22,23,27]\). For the thermal perception, acute exposure to vibration was only significant on the thresholds for cold sensation. This is, however, not in agreement with other studies \([17,28]\) that show temporary changes in warm perception thresholds are measurable or no significant temporary threshold shifts in thermal perception. The discrepancy can probably be ascribed to the use of different experimental setups, temperature, subjects, vibration magnitudes and exposure time as well as contact forces between the hand and vibrating surface.

Threshold recovery measures show that the significant influence on the threshold for cold due to pre-vibration exposure is relatively short, \(~1\) min. For the finger tactile

![Figure 1. Mean changes of the vibrotactile thresholds (dB) for the different periods of vibration exposures as function of time after the exposure.](https://example.com/figure1.png)

![Figure 2. Mean changes of the warmth threshold \(^\circ C\) for the different periods of vibration exposures as function of time after the exposure.](https://example.com/figure2.png)

![Figure 3. Mean changes of the cold threshold \(^\circ C\) for the different periods of vibration exposures as function of time after the exposure.](https://example.com/figure3.png)
perception, the exposure of vibration had a significant effect on the thresholds for 25 min. Moreover, the vibrotactile temporary threshold shifts decrease exponentially with time after exposure, a finding that agrees with earlier studies [29].

All exposures had the same frequency of vibration and the same energy-equivalent frequency-weighted acceleration. According to ISO 5349-1, workers exposed to this type of vibration would have equal risk. The combinations of vibration with different periods of exposure and rest periods had no significant differences on the thermal perception thresholds for the sensation of cold or warmth. The influences on the vibrotactile thresholds due to the different type of exposures were related to the combinations of exposure periods. In general, the current results indicated that there was less temporary threshold shift of vibration exposure when the vibration included rest periods. These findings suggest that breaks in exposure might be beneficial for the response of the vibrotactile sensation but not for the thermal perception. This is inconsistent with the evaluation methods in ISO 5349-1 for the vibrotactile sensation but accurate for the thermal perception.

The results could therefore be interpreted as that intermittent vibration exposure might be less hazardous than continuous exposure to the same vibration. These findings seem to be consistent with the general recommendation and suggest that rest periods may be important for minimizing the risk with occupational exposure to hand-transmitted vibration.

There are some limitations in this study that make generalizing the results problematic. The subjects were young and healthy and therefore the results could not easily be extrapolated to workers who are regularly exposed to vibration or to elderly or to unhealthy subjects. Furthermore, the relation between measurements of temporary thresholds shifts produced by vibration and permanent threshold shift among vibration-exposed workers is not fully known [25]. In the experiment, the exposure time did not exceed 16 min and the corresponding 8-h-equivalent acceleration, A(8), according to current standard is ~0.9 m/s². This is a low daily vibration exposure and studies suggest that symptoms of the hand–arm vibration syndrome are rare or unreported for workers exposed to vibration with an A(8) of <1 m/s² [8]. In the study, only one vibration frequency (125 Hz) was used and therefore no generalization could be done to vibration with other frequencies or to work with hand-held tools that generate vibration with a combination of different frequencies. Moreover, it is well known that different methods for measuring the thresholds [20,23] could affect the results obtained, such as the probe contact force and test environment. However, in this study, the same methods were used for comparing the effects on the thresholds before and after the exposure to vibration. This design of the study has reduced the errors due to the instrumentation set-up and the subject day-to-day variation.

The main conclusions from this study suggest that intermittent exposure to hand-transmitted vibration might be more beneficial for the response of the finger vibrotactile sensation than continuous exposure. This finding is inconsistent with the evaluation methods in the international standard ISO 5349-1 for the vibrotactile sensation, but accurate for the thermal perception.

**Key points**
- Exposure to hand-transmitted vibration produces a temporary change in the thermal and vibrotactile perception.
- Combinations of vibration with different periods of exposure and rest periods significantly influenced vibrotactile perception, but not thermal perception.
- Rest periods may be important for minimizing the risk with occupational exposure to hand-transmitted vibration.

**Funding**
European Commission under the Quality of Life and Management of Living Resources programme (QLK4-2002-02650 VIBRISKS); Swedish Council for Work Life Research (2004-0838).

**Acknowledgements**
The authors would like to thank Asta Lindmark, Fredrik Sjödin, Markus Lindkvist and Andreas Jonsson for their technical assistant.

**Conflicts of interest**
None declared.

**References**


