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Acute Vibrotactile Threshold Shifts in Relation to Force and Hand-Arm Vibration †

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Abstract: Background: to investigate the acute effects of vibration and force level on vibrotactile perception following short-term exposure to hand-arm vibration (HAV). Methods: 12 individuals attended the test, and each of them completed a set of grasping tasks between 10 N and 80 N while being exposed to four intensities of HAV at 125 Hz, ranging from 5.5 to 44.0 m/s^2 (unweighted), for three minutes. The vibrotactile perception threshold (VPT, at 125 Hz) on the fingertip was assessed before and after the exposure. Results: Vibration caused considerable reductions in VPT, and the higher the HAV amplitude, the more the VPT shifted. There were also noticeable VPT shifts brought on by the force increase, but the force increase from 40 N to 80 N could not make more of a difference at higher vibration levels. Conclusions: Vibrotactile perception was sensitive to the vibration level, and was affected by the applied hand force when the vibration intensity was modest. With high vibration levels, the further sensorineural response to the force is limited after the force reaches a certain level.

Keywords: hand-arm vibration; grip exertions; vibrotactile perception; temporary threshold shift

1. Introduction

Employees who work with hand-held vibrating tools may experience health problems as a result of prolonged vibration exposure [1,2]. Their sensory nerves, blood vessels, muscles and joints could be damaged, causing considerable pain and even disability [3,4]. Thus, it is worth investigating the long-term as well as short-term physiological effects of exposure to hand-arm vibration (HAV) for the purpose of preventing related diseases. Among the existing research methods, the measurement of the vibrotactile perception threshold (VPT) has been proposed as a useful technique for screening and diagnosis as it corresponds to the HAV-induced nerve damage that occurs at a relatively early stage [5–7]. In addition, the acute response to vibration exposure could be detected by a temporary shift in the VPT, which was found to be sensitive to the vibrating intensity [8,9]. Apart from the vibration of the tool, the applied force and its impact is another important consideration in exposure assessment. A firm grip not only prevents slipping from the tool [10], but also determines how much vibration energy enters the hand-arm system [11,12]. However, limited attention has been paid to whether the neural response is more responsive to the level of vibration or to the active forces applied. This study aimed to investigate the dependence of temporary nerve function impairment (temporary shift in vibrotactile perception) on exposure to four hand-arm vibrations at 125 Hz and four hand force exertions. It was hypothesized that greater vibration and greater hand forces on the vibrating handle would increase the risk of decline in neurological perception, with comparatively high vibration levels being more crucial for regulation than hand force.

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2. Materials and Methods

An electrodynamic shaker producing vibrations along the *z*-axis was positioned horizontally as shown in Figure 1. A sinusoidal 125-Hz vibration was applied to the right hand through a handle fixed to this shaker. Subjects were required to take a relaxed upright seating position, grasping the handle with a bent-arm posture, while having their left forearms supported at the heart level. Four levels of hand-arm vibration (HAV) stimuli were used as exposure conditions, V = 5.5, 11, 22 and 44 in the unit m/s^2 (unweighted), together with the four levels of grip force applied: F = 10, 20, 40 and 80 in the unit N. Forces measured by the handle's Kistler force sensor were displayed on the screen in front, helping subjects maintain them at the desired levels.

Figure 1. The experimental set-up.

Up to 12 healthy subjects with no prior vibration history participated in the study. Each subject went through all 16 exposure conditions, each containing a period of three minutes of holding the handle. Immediately after the exposure, the participants were instructed to release their hands from the handle and undergo the tests of the VPT, followed by an adequate recovery period (over 20 min). Different exposure situations were conducted in a randomized manner on four separate days for each subject.

The test of the VPT was performed by *HVLab* Vibrotactile Perception Meter for around one minute at 125 Hz on the right index's fingertip. The surrounding contact force was set to 2 N. The elbow of each subject was allowed to rest on a supporter during the test.

3. Results

The baseline VPT calculated for all subjects on the right index fingers was at 0.183 m/s^2 at 125 Hz. The amount of change (TTS) relative to the resting VPT values was studied thereafter, indicating a reduced vibration sensation after the exposure. More shift is believed to be associated with a stronger adverse effect.

Data analysis was conducted using nonparametric tests in SPSS. The Wilcoxon signed rank test was performed between conditions with different exposures.

Figure 2 shows the distribution of TTS in vibratory sensation tested at 125 Hz on the exposed right index finger. After exposure to a 3 min vibration, all individuals experienced a transient rise in the sensorineural threshold. The median TTS was 0.266–0.633 m/s^2 for a small amount of HAV of 5.5 m/s^2 r.m.s. (unweighted) and went up to 1.188–3.391 m/s^2 with the high vibration intensity of 44 m/s^2 r.m.s. (unweighted). Significant differences in TTS can be identified for all four vibration settings regardless of the force level (p = 0.001–0.002, Wilcoxon). In response to an increase in the vibration level by a factor of two, the variations in threshold nearly doubled each time.

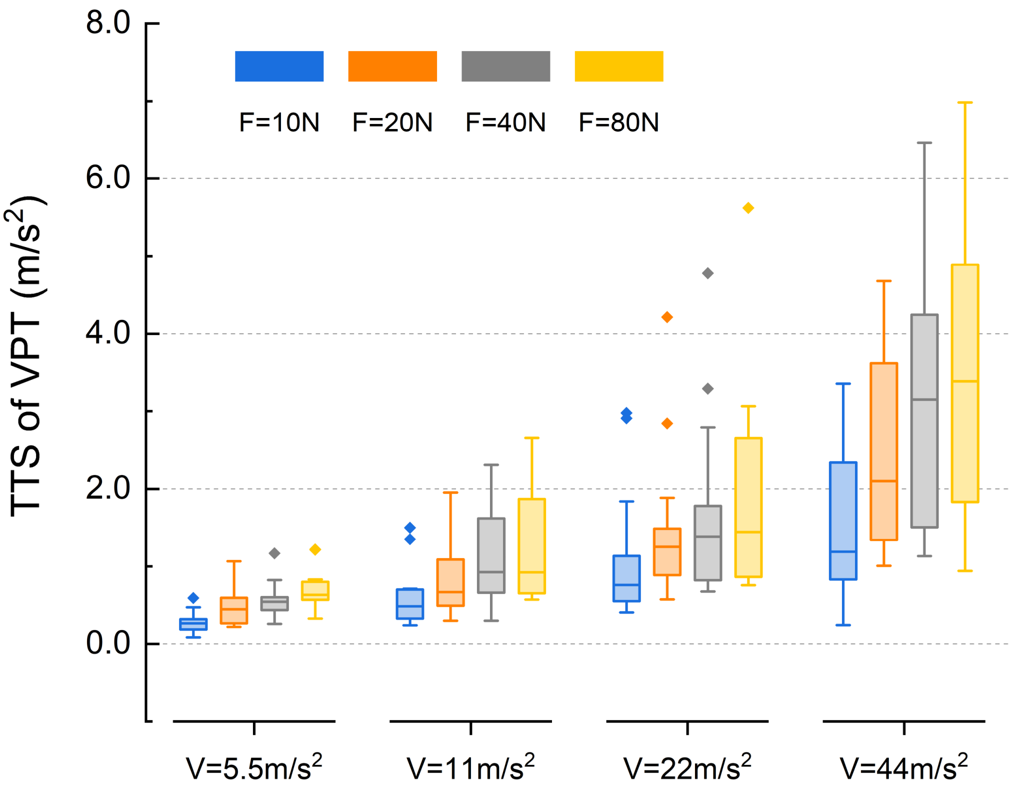

Figure 2. Distribution of the TTS in vibratory sensation as a function of force and vibration. Plotted median values (with interquartile range) of 12 subjects tested at 125 Hz on the right index finger after 3 min of exposure to different levels of grip force and vibration.

The impact on the TTS from the force level appears to follow a similar trend to that of the vibration level. In the presence of a vibration at 5.5 m/s^2 r.m.s. (unweighted), the reductions in perception were significantly different across the four force conditions (p = 0.001–0.006, Wilcoxon). The increase in hand forces was associated with the presence of more shifts in the VPT as shown in Figure 2, though the effect of twice as much force had less of an impact than that of twice as much vibration. At higher vibration levels ($\geq$11 m/s^2, unweighted), there are greater TTS differences with stronger hand forces (p = 0.001–0.006, Wilcoxon), except for the force increasing from 40 N to 80 N, which yielded similar results (p = 0.078–0.173, Wilcoxon).

4. Discussion

Generally, the finger perception thresholds of vibration tend to rise as a function of vibration intensity and hand force level. Exposure to vibration resulted in a clear loss in vibration sensation, which is consistent with the findings of earlier investigations [13]. The VPT results were sensitive to the vibration intensity regardless of the force level; the higher the HAV intensity is, the more vibrotactile perception at the fingertip shifts, which is the same finding as has been reported in previous studies [14,15]. The application of force during vibration exposure also affects the shift in the VPT. With the increase in force, the change in VPT follows an upward trend, similarly to the effect of the vibration level [8,12], suggesting that hand force may create a negative impact on hand sensorineural function. A similar influence of hand force on blood circulation during vibration was found in previous studies [16]. It is worth noting that a further increase in the large hand force was unable to introduce more of a reduction in vibration perception at high vibration levels, which indicates that the effect of force is limited, and may not be completely independent of that of vibration. This could be because the muscle tissue has already sustained the maximum deformation possible with a great vibration intensity, and because further increases in hand force will no longer be able to expose more receptors to the vibration level and cause additional sensation loss. In the case of both the vibration and force being at high levels, the VPT was still substantially affected by the vibration. The results strongly confirm the great influence of vibration on sensory nerves and underline that the regulatory role of the force applied should not be underestimated.

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