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EFFECTS OF VIBRATION FREQUENCY AND DURATION ON EYE-HAND COORDINATION IN POINTING TASKS

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Abstract - The effects of high frequency (100, 200 Hz) hand vibration on simultaneous eye and hand pointing tasks were investigated in ten subjects. The pointing task was performed with and without direct visual control of the hand before and during short term (2 min.) hand vibration or before and after 10 min. hand vibration. Vibration induced an increase in hand pointing constant error and error variability. These alterations were more particularly pronounced for the 100 Hz vibration and when the hand was masked. The eye gaze constant error and error variability increased during and immediately after vibration exposure. These results indicate that vibration similar to hand-tool vibration affects movement precision and the coordination of hand and eye movements; more specifically in absence of visual control of the hand.

INTRODUCTION

Visual control of hand movement is essential in occupational activities requiring precise manipulation. The coordination of eye and hand movements is required in these tasks. Visual, proprioceptive and exteroceptive information contribute to the control of the complex coordination processes [1], [2]. Hand vibration has been shown to alter continuous manual control and oculomanual coordination [3]. There is evidence that these perturbations of sensory motor activities result from vibration-induced changes in sensory messages [4], [5], which deeply affect the functioning of the neurosensory mechanism underlying motor control [6], [7], [8]. These alterations were found to be frequency dependent [7], [8]. In addition, earlier data show that visual control of hand movements may counteract vibratory effects in specific contexts [3].

The question then arises as to how alterations of manual performances and eye-hand coordination are related to vibration frequency. In particular, which vibration frequencies would have less influence on oculomanual coordination? Furthermore, as visual control may not be efficient in all situations it is of interest to assess its role in simple pointing tasks, which are frequently performed under vibration exposure in various powered hand tool manipulations.

The present study describes the changes in coordinated eye-hand pointing tasks during short term and after long term hand vibration exposure for two vibration frequencies.

METHODS

Subjects

Ten right handed subjects aged 20 - 40 years participated in the experiment as paid volunteers. All subjects were in good physical condition, free from any known neurological or musculoskeletal disorders and had good vision without optical aide. The experiment was approved by the ethic committee of the University of Michigan School of Public Health. Prior the experiment each subject read and signed an informed consent form.

Experimental Situation

The subject was seated on an adjustable armchair in front of a display panel placed 57.3 cm from the eye. Eleven light emitting diode (LED) arranged in a cross shape and spaced by 5 cm (5° viewing angle) served as visual targets. Eye position was monitored using an infrared optoelectronic device. Hand pointing position was measured by a two-dimensional sonic device fixed to the panel. The pointing device consisted of a handle with a pointer running off the top at a right angle to the axis of the handle. The handle contained a cam load vibrator. Vibration was applied to the dominant hand of the subject using either the self-contained vibrator located in the handle of the pointing device or a vertical handle fixed to an electromagnetic vibrator. In this later case, the handle was equipped with a dynamometer to display the grip force on a digital voltmeter. Sinusoidal vibration of 100 Hz and 200 Hz with displacement amplitude of 0.2 mm were used. The task consisted of pointing below the horizontal targets with the pointer held in the right hand. During a pointing trial each horizontal target was illuminated ten times in a random order. The target was turned on for one second; three seconds separated two consecutive target presentations. A pad, on which the subject pointed, was located 7 cm below the horizontal LEDs. A mark placed under the center target to indicated the starting location of all pointing movements. The subjects were instructed to simultaneously move the eye and the hand and, perform the hand motion as quickly as possible while emphasizing accuracy.

Procedure

The subject performed practice trials before the experiments. Two sets of experiments were carried out on non-consecutive days: per-vibration and post-vibration pointing.

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In the "per-vibration pointing" experiment the task was performed before and during hand vibration with the hand in sight or the hand out of sight, masked by an opaque screen. In this latter case, a hole in the screen allowed vision of the center mark. Data was collected for a total of eight trials (2 test situations x 2 frequencies x 2 visual conditions). A 5 minute rest period separated two consecutive trials, and a 15 minutes rest period separated two vibration exposures.

In the "post-vibration pointing" experiment the task and visual conditions were identical to the one described above. The pointing performance was tested before (T_C), immediately after (T_0), and 5 (T_5) and 10 min (T_{10}) after a 10 min. vibration exposure. During the vibration period the subject grasped the handle and exerted a grip force of 5% MVC during 5 sec and relaxed for 25 sec. Visual feedback was provided by the digital voltmeter connected to the dynamometer. Data was collected for a total of 16 trials (4 test situations x 2 frequencies x 2 visual conditions). A 15 minutes rest period separated two vibration exposures.

Recording and analysis

The horizontal eye position signals were sampled at 1000 Hz and recorded by a computer. The horizontal coordinate of the pointing location and the pointing movement time were recorded simultaneously by another computer. Repeated measures analysis of covariance (ANACOVA) treating the subject as a random blocking factor was performed on the eye and hand constant error (mean end-point from the center of a target), error variability (absolute error = |constant error| and standard deviation of absolute error), and hand movement time to characterize the effects of hand vibration on the visuo-manual task.

RESULTS

I. Per-Vibration Pointing

The ANACOVA performed on the hand and gaze constant errors, absolute error and hand movement time indicate that vibration, vibration frequency and visual conditions had a significant influence on hand pointing and eye gaze precision and, eye-hand coordination. The movement time was also affected by hand vibration.

Hand movements: Figure 1 (left panels) illustrates the influence of hand vibration on the constant error for each visual condition. In the control situation (no vibration) the constant error increases when the hand is masked. In addition, the error variability also increases significantly when the hand is masked. Changes resulting from vibration exposure are as follows. Changes in the constant error were significant only for the most eccentric targets (±10°, ±15°). The average magnitude of the shift in pointing position induced by the 100 Hz vibration is 1.2 mm when the hand is visible and 3.7 mm when the hand is masked. The absolute error increases ($p < 0.05$) from 4.9 mm to 5.9 mm during 100 Hz vibration when the hand is visible. In the control situation, the standard deviation of the absolute error was larger ($p < 0.05$) for the mask (± 6.6 mm) than the no-mask condition (± 3.5 mm). Probably because of this large increase in error variability before exposure, no significant variation in error variability was observed during vibration when the hand was masked. The movement time decreases significantly only during 100 Hz vibration (Table 1). The 200 Hz vibration had no significant influence.

Eye movements: Figure 1 (right panels) illustrates the influence of hand vibration on the gaze constant error for each visual condition. Changes in the constant error (mean = 0.25° for both visual conditions) are only significant for large amplitude movements (±10°, ± 15°). The absolute error increases significantly ($p < 0.05$) by 0.2° for the 100 Hz vibration in the no-mask visual condition and is not affected by the 200 Hz vibration. In this visual condition (no-mask), the error variability increases significantly from ± 0.68 (no vibration) to ± 0.78 (100 Hz vibration). No significant changes in absolute error or error variability where observed when the hand was masked. A visual analysis of the eye movement traces did not reveal a change in the saccade pattern under vibration exposure.

II. Post-Vibration Pointing

The ANACOVA indicated that vibration and visual conditions had a significant influence on hand pointing and eye gaze precision, and eye-hand coordination. The visual condition plays a significant role, more specifically after vibration exposure. Vibration frequency significantly influenced the task in specific situations.

Hand movements: Figure 2 (left panels) illustrates changes in the constant error observed immediately after vibration exposure (T_0) for each visual condition. A shift in hand pointing position is observed when the hand is masked (lower left panel). This error corresponds to an undershoot of the targets. The constant error, the absolute error and error variability are not affected by the visual conditions in the control situation. Changes resulting from vibration exposure are as follows. Changes in the constant error are significant only for the most eccentric targets (±10° and ±15°). This error is significantly affected after vibration only when the hand is masked. Vibration frequency does not have a significant ($p >> 0.05$) influence on that type of error. The average magnitude of the shift in hand pointing position induced by vibration is 4.7 mm when the hand is masked. In this visual condition the absolute error increases significantly from 5.1 mm to 7.2 mm. The magnitude of the shift in pointing position observed immediately after vibration (T_0) remains approximately the same up to 10 min. after vibration exposure when the hand is masked, while no significant changes are observed when the hand is visible (Figure 3).

The error variability increases by more than 60% after vibration exposure when the hand is masked. This increase persists up to 10 minutes after exposure. No changes in variability are observed after vibration exposure when the hand is visible. The movement time is not significantly affected after vibration exposure.

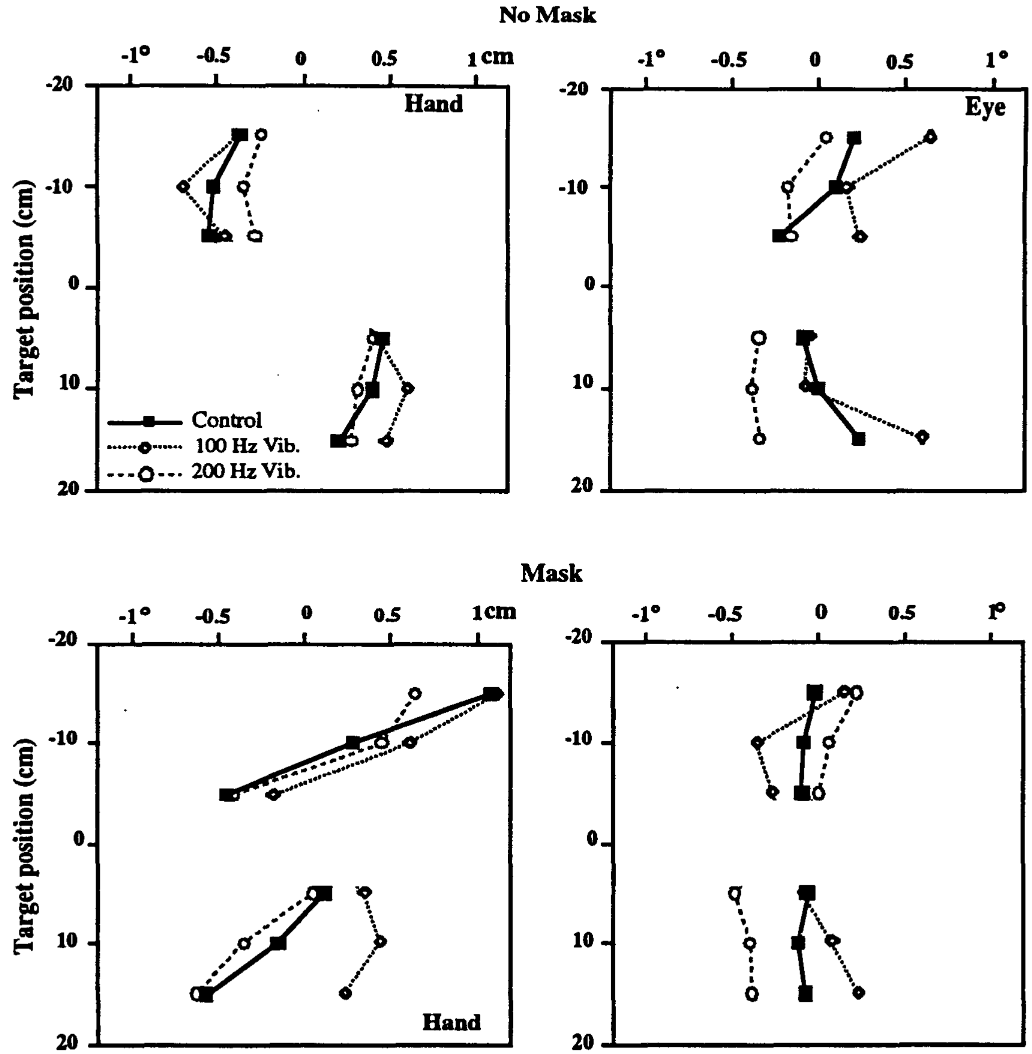

Fig. 1. Hand and eye constant errors during vibration exposure. Hand not masked (upper panels), hand masked (lower panels). The errors (horizontal axis, 1 cm = 1° of visual angle), are presented for each target (vertical axis). Each symbol indicates the magnitude of the error relative to the center of the target.

TABLE 1
Movement time

Vibration	Hand movement time (ms)	
	No-mask	Mask
Control (no vibration)	635 ± 210	605 ± 193
100 Hz	550 ± 159 *	546 ± 139 *
200 Hz	645 ± 188	602 ± 187

* significant decrease ($p < 0.05$)

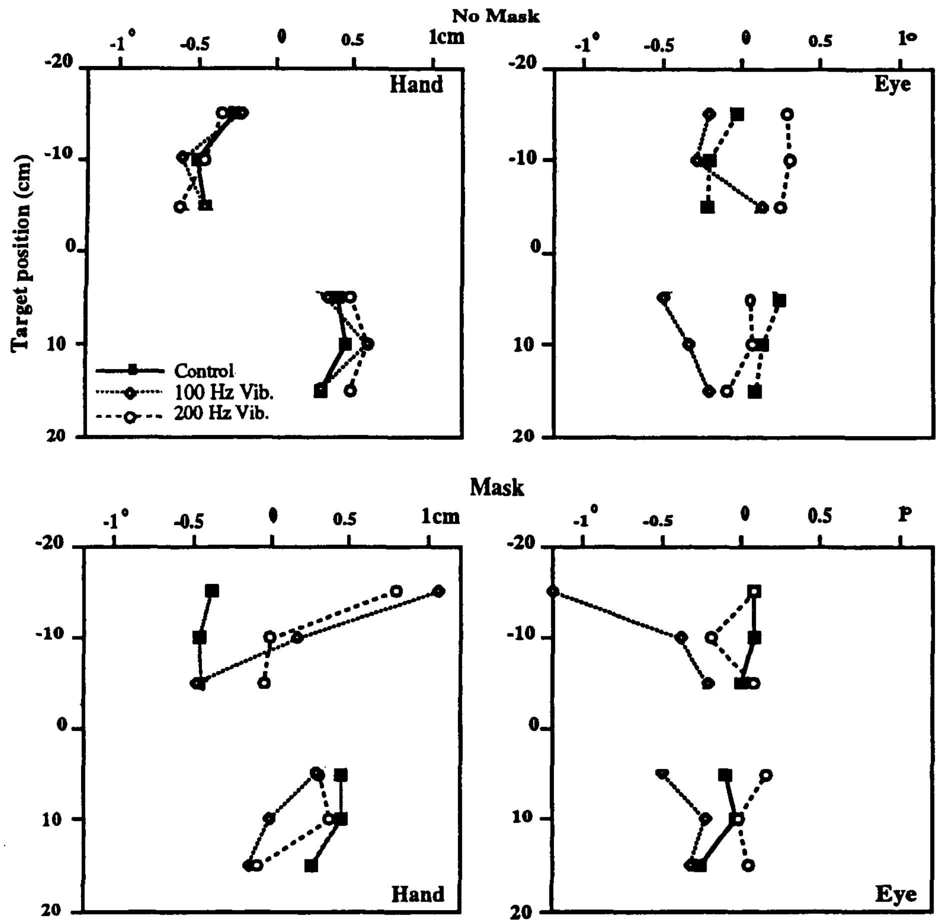

Fig. 2. Hand and eye constant errors immediately after vibration exposure. Representation identical to Figure 1.

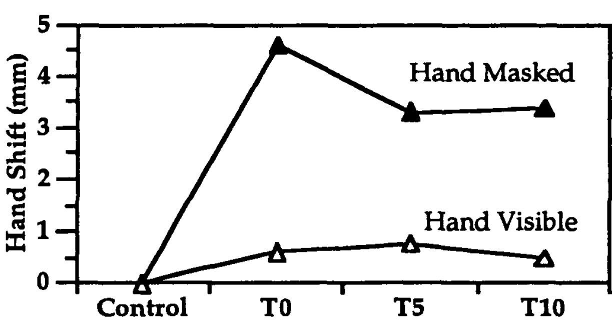

Fig. 3. Average shift in hand pointing position observed after vibration exposure.

Eye movements: Figure 2 (right panels) illustrate the influence of hand vibration on the gaze constant error for each visual condition. Changes resulting from vibration exposure are as follow. The average magnitude of gaze shift are 0.35° and 0.25° when the hand is not masked and masked, respectively. These shifts mostly correspond to target undershoot when the hand is not masked (Figure 2 upper right panel), while they are not specifically oriented when the hand is masked (Figure 2 lower right panel). The constant error was larger ($p < 0.05$) for 100 Hz than 200 Hz vibration only when the hand was not masked. The absolute error increases significantly ($p < 0.05$) by 0.17° and 0.13° immediately after 100 Hz vibration exposure when the hand is not masked and masked, respectively. Furthermore, the standard deviation also increases in the same situations. No significant changes were observed 5 min. after vibration exposure; hence, hand vibration may not have long lasting effects on the control of eye movements

DISCUSSION

The present study investigated the per and post-effects of hand vibration exposure on a simple visuo-manual pointing task. There were four major findings. First, impairments of hand pointing and eye gaze show that hand vibration can affect the precision of hand movement and coordination of the eye and the hand when they are involved in the same task. This finding, which agrees with previous results concerning visuo-manual control, confirms the influence of hand proprioception on eye-hand coordination. Furthermore, only large amplitude movements (≥ 10°) are affected. Second, hand and eye movements are generally more strongly affected by 100 Hz than 200 Hz vibration. Third, changes in performance observed during and after vibration exposure when the hand is masked underline the role of the visual feedback in vibratory environments. Fourth, the persistence of the constant error of the hand movements 10 min after vibration exposure only when the hand is masked indicate that vibration may lead to a loss of the proprioceptive reference that is not compensated by a visual input.

Alteration of eye-hand pointing

The results presented in Figure 1 and 2 show that vibration can induce a shift in hand pointing and eye fixation, before and after vibration exposure. These errors are accompanied by an increase in error variability. The general trend indicates that 100 Hz vibration seems to produce the strongest effects. The vibration-induced alterations of coordinated hand and eye movements observed in the present context are in line with previous results showing impairments of continuous tracking movements [3]. They confirm that vibration-induced alteration of sensory information issued from somesthetic mechanoreceptors can contribute to a decrease in movement precision and that frequency effects are related to the receptors sensitivity to the frequency of the vibratory stimulation. Primary muscle spindle receptors, which provide limb position information, are extremely sensitive to vibration frequencies up to 100-120 Hz [4], while cutaneous receptors, also involved in motor control processes, are sensitive to vibration up to 250 - 300 Hz [9], [4]. Thus, the weaker influence of 200 Hz vibration suggests that the impairment of performance has predominantly a muscle proprioceptive origin.

The alteration of eye movements indicates that vibration is able to affect the coordination of the hand and the eye in pointing tasks, despite the fact that the target was always visible. The role of hand and arm proprioceptive afferents in eye movement control, proposed by several authors [1], [3], [10], suggests that the alteration of the information mediated by these pathways is most likely responsible for the changes in eye fixation error and error variability observed during and immediately after vibration exposure.

In the present context (target visible), it can be proposed that eye gaze alterations result most probably from the sensory noise generated by the vibratory stimulus. In fact, no specific direction in fixation shift and no obvious changes in eye movement pattern were observed. Furthermore, vibration frequency had a limited impact on eye movements. We assume that the visual feedback provided by the target light counteracted most of the influence of the "distorted" hand proprioceptive information. Despite the significance of the alterations it is important to remark that fixation errors are relatively small (0.25°), which do not compromise foveal vision of the targets.

Visual feedback of the hand

The visual feedback of the hand did not totally prevent the alteration of hand aiming position during vibration exposure. This "residual" effect is probably due to the fact that the hand aiming location was 7° below the visual target. As subjects were requested to focus on the visual targets, the hand was beyond the limit of the foveal field (≈ 2°). Thus, the precision of the foveal system was not available to fully compensate the vibratory effects described above. Nevertheless, peripheral vision did play a significant role, as the alterations of hand movements were more pronounced in the absence of hand visual feedback.

Post-vibration recovery

The performance recovery time seems to be less than 5 minutes for both hand pointing when the hand is not masked and eye fixation in all visual conditions. However, the hand pointing constant error and the increase in variability of the absolute error persist throughout the observed post-vibration period. This data show that in the absence of visual feedback, the vibration-induced bias in movement amplitude is not corrected by a recalibration of the hand controller. The persistence of the error suggests that the pre-vibration reference is lost during vibration exposure. In the absence of a visual information the subject tends to use the last available proprioceptive information. A similar effect has been observed in an earlier study of torque control under whole-body vibration without visual feedback [11]. In that study, maintaining a constant torque by pressing with the foot on a pedal was biased by a vibration applied to the whole body. The increase in torque during vibration was not perceived by the subject and the torque remained higher after vibration exposure. We may assume that despite subject training, the subject may use the first series of movements performed immediately after vibration as a calibration for the subsequent series. Furthermore, the existence of a long lasting phenomenon inducing the persistence of muscle contraction following vibration exposure has been reported by Ghilodes et al. [5]. These authors suggested that the phenomenon is related to changes in central mechanisms triggered by the vibration-induced activity of muscle spindle receptors. The contribution of these mechanisms to the delay of a recalibration of movement amplitude cannot be ruled out in the present case.

Conclusions

The absence of visual control of the hand has detrimental effects on aiming precision during and after vibration exposure. Although visual feedback may help to compensate performance decrement induced by vibration exposure, this compensation is not complete during the vibration period. Hence, visual control of the hand appears to be a necessary but not sufficient condition to limit the vibration-induced degradation of manual tasks. Furthermore, pointing performances seem less affected by high vibration frequencies (200 Hz). These remarks are of particular importance in the design of the workplace and powered hand tools. First, visual control of the hand holding a vibrating tool should not be interrupted in tasks requiring aiming movements. Second, high frequency vibration (> 200 Hz) are preferable since they tend to have less influence on motor performances and are easier to attenuate.

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