11TH INTERNATIONAL CONFERENCE ON HAND-ARM VIBRATION

RELATIONSHIPS BETWEEN PSYCHOMETRICS, EXPOSURE CONDITIONS, AND VIBRATION POWER ABSORPTION IN THE HAND-ARM SYSTEM

Thomas W. McDowell, Michael L. Kashon, Daniel E. Welcome, Christopher Warren, Ren G. Dong

Health Effects Lab, National Institute for Occupational Safety & Health, Morgantown, WV (USA)

Abstract

This study hypothesized that reliable and quantifiable relationships may exist between the vibration power absorbed by a given component of the hand-arm system and the perceived vibration intensity at that component. As a step to test this hypothesis, this study performed a preliminary exploration into relationships among subjects' location-specific psychometric responses, hand-handle coupling conditions, vibration exposure conditions, and vibration power absorption (VPA). The experiment employed 24 human subjects. Two sinusoidal vibration exposure conditions (16 Hz, 8.9 m/s^2 rms; and 125 Hz, 62.9 m/s^2 rms) and two hand actions (20 N grip-only; and a combined 20 N grip and 40 N push) were used in the experiment. A seven-point Likert scale was used to categorize the subjective sensation responses to the vibration exposures. A recently-developed computer model of the hand-arm system was used to predict the VPA distributions at the fingers, the back of the hand, the palm and wrist, the arms, and the shoulder. The correlation between the VPA and the subjective sensation at the corresponding locations was examined. The results of this study suggest that location-specific vibration perception has some association with location-specific VPA.

1. Introduction

Effective risk assessment standards are necessary to help protect workers from potentially harmful workplace hand-transmitted vibration (HTV) exposures. The current international standard ISO 5349-1 [1] is largely based on subjective sensation data and limited epidemiological data [2,3]. In addition to these two foundations, Griffin [4] suggested that the further development or improvement of the standard should be based on two more scientific foundations: (1) biodynamics of the hand-arm system; and (2) physiological and pathological mechanisms of vibration-induced disorders. Moreover, more reliable experimental data from subjective sensation studies and epidemiological studies are required to further develop and improve HTV risk assessment methodologies. The conceptual model of vibration exposure and health effects proposed by R.G. Dong et al. [5] indicates that the study of the biodynamics of the hand-arm system encompasses the examination of vibration-induced mechanical stimuli inside the tissues of the system; thus, it is directly associated with the other three scientific foundations. Whereas some evidence of the associations among these foundations has been reported [6,7], their specific relationships remain interesting and important topics for further study.

In a recent study, R.G. Dong et al. [7] found that frequency weighting based on the vibration power absorption (VPA) of the entire hand-arm system was very similar to the psychometric-based ISO weighting. Because the ISO weighting was based on global sensation perception, this observation suggests that total VPA may be directly related to the overall sensation. The researchers further hypothesized that reliable and quantifiable relationships exist between the vibration power absorbed by a given component of the hand-arm system and the perceived vibration intensity at that component. Knowledge of the relationships among exposure conditions, location-specific vibration perception, and the distribution of power absorption could enhance the understanding of the mechanisms of vibration-induced discomfort and disorders and lead to the development of improved standards for assessing and controlling hand-transmitted vibration exposures and their effects. This study is a preliminary investigation into those location-specific relationships.

2. Methods

2.1 Subjective Perception Experiment

This study was designed to explore relationships between subjects' location-specific psychometric responses, hand-handle coupling conditions, vibration exposure conditions, and vibration power absorption. The experiment employed 24 human subjects. The basic approach was to expose the subjects to a set of specific vibration and posture conditions and have the subjects quantify their perception of the vibration intensity. The set of vibration exposures and hand-handle coupling conditions was the same for all subjects. Sinusoidal vibrations of 16 Hz (8.9 m/s^2 rms) and 125 Hz (62.9 m/s^2 rms) were presented to the handle in line with the subject's forearm direction (z_h-axis). During a trial, a subject applied either a grip-only action (20 N) or a combined grip (20 N) and push (40 N) action. The four vibration and coupling action combinations were independently randomized for each subject.

Following the exposures, subjects were asked to rate the intensities of the vibration at eight body locations along the path from the fingers to the head (fingers, wrist, forearm, upper arm, shoulder, neck, back of the head, and face). A seven-point Likert scale was used to categorize the subjective sensation responses [8]. Following the first action at a specific frequency, the subjects were asked to identify the areas where they felt the most and least vibration; those areas were assigned ratings of seven and one, respectively. The other body locations were rated on the seven-point scale in relation to the two extremes for that particular exposure. After the second action at that frequency, the rating process was repeated. The subjects were asked to compare the sensations for the two actions for each frequency. If the subject sensed a difference in vibration intensity between the two actions at a given frequency, the sensation values were adjusted by half-point increments by up to a maximum of two points.

The perception data were analyzed with SAS/STAT software (version 9.1 of the SAS System for Windows, Cary, NC). Scores were analyzed independently at each location using the Kruskal-Wallis nonparametric ANOVA. Where appropriate, pair-wise comparisons between groups were performed with the Wilcoxon rank-sum test.

2.2 Estimation of the distribution of vibration power absorption

The biodynamic response and the vibration power flowing into the fingers and into the palm of the hand can be quantified using the method described by R.G. Dong et al. [9]. Briefly, an instrumented cylindrical handle is used to measure the subject's response to controlled vibration inputs while the subject applies specific grip and/or push forces to the handle. Measurements can be taken at either the finger side or the palm side of the hand. Typically, finger side and palm side measurements are evenly split; a set of measurements is taken on one side; then the handle is rotated 180° to take measurements on the opposite side under the same vibration exposure and coupling force conditions. In this fashion, the finger side and palm side VPA can be determined.

The vibration power flowing into the fingers and into the palm may not be fully absorbed in those components or structures; some of the vibration power may pass through those structures to be dissipated by downstream components and structures. Currently, it is infeasible to directly measure the distributed VPA in different components of the hand-arm system. Alternatively, R.G. Dong et al. [10] have recently proposed a modeling approach to estimate distributed VPA values. The five degree-of-freedom (DOF) model of the hand-arm system used in this study is depicted in figure 1.

This model makes it possible to predict VPA distribution. Specifically, the vibration power dissipated by viscous element c_4, which is directly related to relative movement between masses M_2 and M_4, is used to represent the power absorbed within finger tissues (P_4). In similar fashion, P_3, the power dissipated by c_3, directly relates to the power absorbed in the palm-wrist-forearm substructures. P_2, the power absorbed by c_2, is used to represent the VPA distributed in back of the hand, the metacarpo-phalangeal joints, and surrounding tissues. The power dissipated by c_1 relates to power absorbed in tissues in the forearm and upper arm structures (P_1). The power dissipated by c_0 relates to the vibration power absorbed by tissues in the shoulder, neck, head, and the upper body (P_0).

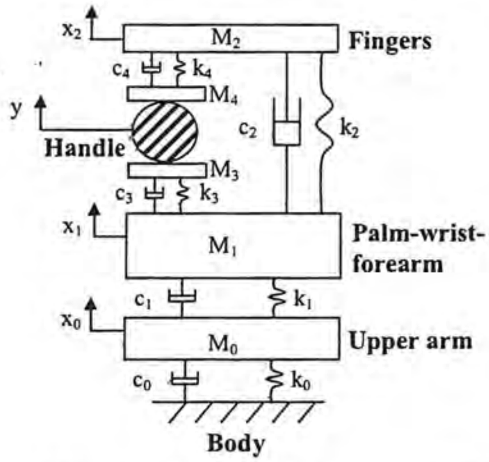

Figure 1 - The five-DOF model of the hand-arm system used to quantify location-specific VPA

The model parameters can be determined using the driving-point biodynamic response data measured at the fingers and the palm of the hand [10]. Unfortunately, because this experiment examined the biodynamics at only two vibration frequencies, the full set of experimental data required to determine the model parameters for this study's two specific test conditions (20 N grip-only, and 20 N grip plus 40 N push) are not presently available. For a preliminary analysis, the modeling data reported by J.H. Dong et al. [11] based on experimental data collected under the combined 15 N grip and 35 N push condition and the 30 N grip plus 45 N push condition were used to estimate the model parameters for the combined 20 N grip plus 40 N push condition. Those estimated model parameters are listed in table 1.

Table 1 - Model parameters for the combined 20 N grip and 40 N push condition

Mass (kg)		*Stiffness (N/m)*		*Damping (Ns/m)*	
M_0	5.7810	k_0	15,963	c_0	148
M_1	0.9117	k_1	2,155	c_1	159
M_2	0.0812	k_2	3,728	c_2	28
M_3	0.0299	k_3	43,963	c_3	94
M_4	0.0111	k_4	72,933	c_4	88

3. Results and Discussion

Figure 2 illustrates the average vibration perception scores for the four exposure conditions at each of the eight body locations. As seen in the figure, the 125 Hz exposures produced the highest perception scores in the fingers; those 125 Hz finger scores were significantly higher than the 16 Hz finger scores ($p<0.001$). The 16 Hz scores were significantly higher ($p<0.001$) than the 125 Hz scores at all other locations except the wrist where no significant difference was found. The 125 Hz averages steadily decreased with distance from the fingers. Coupling action had little effect on the 125 Hz scores; only at the forearm were the two means significantly different ($p<0.001$). For the 16 Hz exposures, means for the grip only and combined grip and push actions were significantly different at the fingers, upper arm, shoulder, and neck ($p<0.001$).

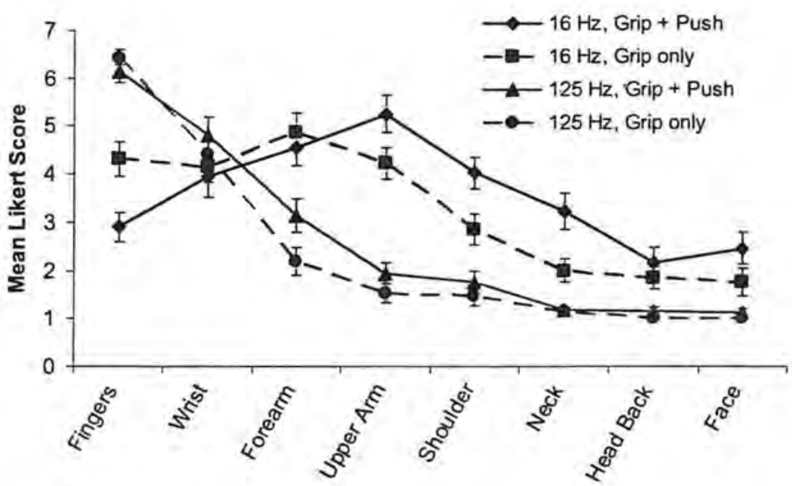

Figure 2 - Vibration perception score averages (n=24) at each body location under each exposure condition. (Y error bars = ±SEM)

Figure 3 illustrates the VPA distribution under the combined grip and push action as predicted by the model. At 16 Hz, vibration power is largely distributed in the forearm and upper arm; this result is consistent with the subjects' perception scores at these locations. The basic trend of the VPA distribution at this frequency is also fairly consistent with the distribution of the location-specific vibration perception scores under the combined grip and push action.

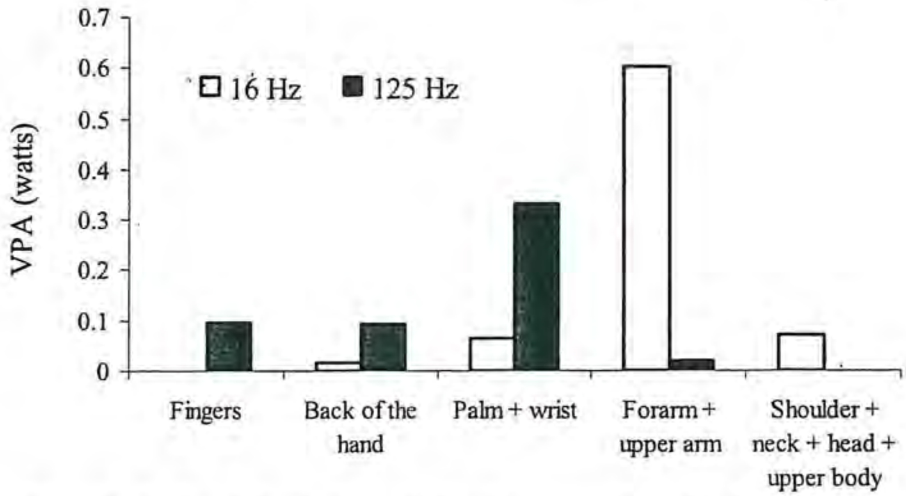

Figure 3 - Predicted distributions of vibration power absorption for the combined 20 N grip and 40 N push condition

Figure 4 shows the comparison of the VPA values directly measured at the fingers and at the palm of the hand. At 16 Hz, the VPA measured on the finger side under the grip-only action (0.15 W) is much greater than that with the combined action (0.02 W) ($p < 0.001$); this suggests that the vibration power absorbed by the fingers under the grip-only action is greater than that under the combined action. This may explain why the finger perception score for the grip-only action is greater than that for the combined grip and push action, as shown in figure 2.

As shown in figure 3, at 125 Hz, vibration power is almost entirely absorbed in the hand and wrist. That is to say, very little of the 125 Hz vibration power is dissipated beyond the wrist. Furthermore, the fingers possess higher concentrations of mechanoreceptors than do downstream structures. Also, because of their relatively small volume, the highest power absorption density likely occurs in the fingers. These observations may explain the higher finger vibration perception scores. At 125 Hz, VPA at the fingers under the grip-only action (0.17 W) was only marginally different than that observed under the combined action (0.14 W). This is consistent with previous research [9], which reported that VPA at the fingers is practically independent of coupling action. Subjects might not reliably notice such a small difference as is reflected in the above-noted 125 Hz finger perception scores.

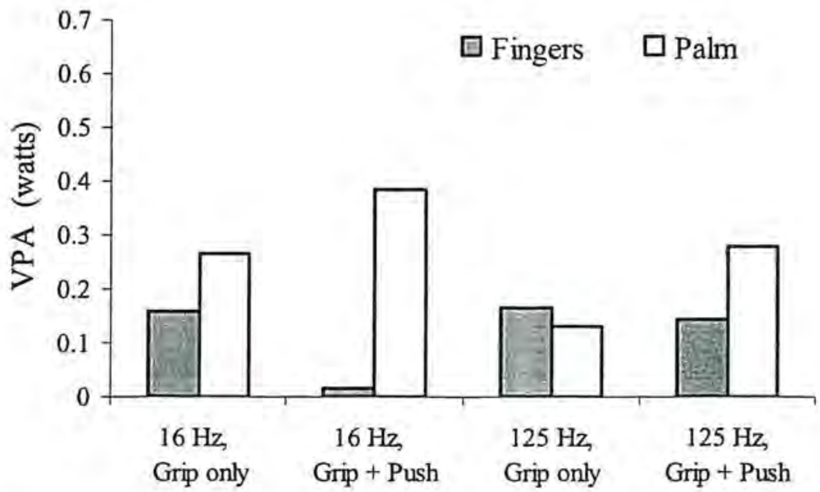

Figure 4 - Comparison of VPA values measured at the fingers and at the palm under the grip-only and the combined grip and push actions

4. Conclusions

The results of this study suggest that location-specific vibration perception has some association with location-specific VPA. This further suggests that location-specific VPA may be used to predict location-specific discomfort and vice versa. As more data become available and hand-arm system models are improved, more accurate predictions of VPA distribution will result. As these models mature, knowledge of vibration power absorption distributions and vibration perception may be used to help generate location-specific frequency weightings for assessing location-specific discomfort and risks associated with hand-transmitted vibration exposure.

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Proceedings edited by

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P. Nataletti, G. Moschioni