POSTURE-RELATED CHANGE IN FREQUENCY WEIGHTINGS DERIVED FROM VIBRATION POWER ABSORPTION OF THE HAND-ARM SYSTEM

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1. INTRODUCTION

Workers use various hand-held power tools in a variety of hand-arm postures during their operation. However, the evaluation method of effects of exposure to hand-arm vibration (HAV) on health, specified by ISO5349-1(2001), does not consider the effects of hand-arm posture on frequency weightings.

Frequency weightings derived from total power absorption of the hand are shown to correlate well with the ISO weightings based on subjective sensation or discomfort (Dong et al., 2006). The aim of this study is to examine the effects of hand-arm postures on the frequency weightings derived from the vibration power absorption (VPA) of the hand. To calculate the VPA-based frequency weightings, the mechanical impedance was measured for twelve male subjects exposed to a random vibration along the Z_h axis. This study considered five arm posture conditions that consist of two elbow postures (horizontally stretched straight and bent by 90 degrees) in combination with three forearm postures (pronated, neutral, and supinated).

2. SUBJECTS AND METHOD

2.1. Apparatus

The single-axis hand-arm vibration test system used in this study included an electro-dynamic shaker (VE-100S; IMV Corporation, Osaka, Japan) that can generate Z_h axis vibration. A handle instrumented in the system had a circular cross-section with a diameter of 40 mm and an effective grip length of 100 mm. It was connected to the shaker shaft so that the centerline axis of the handle was vertically oriented. This handle consisted of the handle base and measuring cap, between which two piezoelectric single-axis force sensors (9212; Kistler Inc., Winterthur, Switzerland) were sandwiched along the centerline of the handle, to measure the grip force acting between the base and the measuring cap. Signals from these two force sensors were summed up to obtain the total grip force. Also an accelerometer (356A12; PCB Piezotronics, Inc., New York, USA) was secured to the center of the measuring cap to measure the vibratory acceleration at the handle. The push force applied to the handle through the hand was measured by using a force plate.

2.2. Subjects

The experiments were performed with twelve healthy male subjects in their twenties. None of the subjects had any experience of exposure to high levels or long periods of hand-arm vibration occupationally or in their leisure time activities. The right hand was used for the test.

All the subjects underwent an explanation of the test procedure and gave their written informed consent to participate in the study. The experiment was approved by the Research Ethics Committee of Japan National Institute of Occupational Safety and Health.

2.3. Method

The vibration signal used in the experiments was a pseudo-random vibration in the frequency range of 10 Hz to 1,250 Hz with a flat power spectrum density (PSD) of 1.0 $(m/s^2)^2/Hz$, which corresponds to an unweighted acceleration magnitude of 35.2 m/s^2 (r.m.s.).

Table 1. Hand-arm postures considered in this study.

Posture index	Elbow	Forearm
BP	Bent	Pronated
BN	Bent	Neutral
BS	Bent	Supinated
SP	Straight	Pronated
SN	Straight	Neutral

As summarized in Table 1, this study considered five hand-arm postures by combining three forearm postures with two elbow postures. Three forearm postures considered in this study included 1) pronated posture in which the forearm was rotated by 90 degrees with the palm facing inferiorly, 2) neutral posture in which the forearm was maintained so that the palm faced medially, and 3) supinated posture in which the forearm was rotated by 90 degrees with the palm facing upward. The elbow was either stretched straight with the forearm and upper-arm horizontally maintained, or bent by 90 degrees so that the upper-arm was vertically maintained. During the measurements, the subjects were asked to keep the hand-arm untouched to the body.

The subjects with these postures were exposed to Z_h axis hand-arm vibration. Mechanical impedances in the Z_h direction were measured at the finger and at the palm side. The total BR parameters of the entire hand were obtained by summing up the BR parameters measured at the both sides. The subjects were asked to grasp the handle with a grip force of 30N in combination with a push force of 50N. The dynamic force and acceleration in the Z_h direction were measured at the measuring cap of the handle. The data gathering was performed with a data acquisition system (Type3109; Brüel & Kjær; Nærum, Denmark).

The results obtained in this study were analyzed and were expressed at the one-third octave band center frequencies ranging from 10 to 1,000 Hz. For each measurement, data collection lasted 30 seconds.

2.4. Calculation of VPA-based weighting factors

The driving-point mechanical impedance (DPMI) at the hand-arm system is defined as a ratio of the dynamic force V(ω) to the vibration velocity V(ω):

$$DPMI(\omega) = F(\omega)/V(\omega) \quad (1)$$

According to the normalization technique used in a previous study (Dong et al., 2006), the VPA-based frequency-weighting factor W_{VPA} can be given as a function of the frequency in the following equation:

$$W_{VPA}(\omega) = 0.958 \cdot \frac{\omega_{ref}}{\omega} \cdot \sqrt{\frac{\mathrm{Re}[DPMI(\omega)]}{\mathrm{Re}[DPMI(\omega_{ref})]}} \quad (2)$$

where ω_{ref} is the frequency of the reference impedance. In this study, the impedance magnitude at 12.5 Hz was taken as the reference.

3. RESULTS

Under elbow-bent posture, no significant difference was observed for effects of forearm postures on the MI at frequencies from 10 to 25 Hz and from 160 to 250 Hz. At frequencies ranging from 40 to 125 Hz, forearm pronation was statistically significant for the neutral / supinated forearm posture ($p<0.01$). In contrast, the neutral forearm posture was significant for the forearm pronation and supination. Under elbow-stretched posture, difference in the MI was significant in between the pronated and neutral forearm posture at frequencies of 10-25 Hz ($p<0.01$), 63-100 Hz ($p<0.01$), 315-400 Hz ($p<0.01$), and 630-1,000 Hz ($p<0.05$). Under pronated forearm posture, the MI measured with the elbow-bent posture was observed to be significantly different from that with the elbow-stretched posture in the frequency bands, 1-20 Hz ($p<0.01$), 32 Hz ($p<0.05$), 63-125 Hz ($p<0.01$), and 250 Hz ($p<0.05$). Also under neutral forearm posture, the MI measured with elbow-bent posture was significantly different from that with the elbow-stretched posture in the entire frequency range of 10-1,000 Hz ($p<0.01$), except in the frequency bands of 20, 125, and 160 Hz (Figure 1).

Under the elbow-stretched postures, the VPA-based weighting factors were significantly lower than the ISO weighting factors at frequencies ranging from 12.5 to 1,000 Hz ($p<0.01$). These basic trends observed in VPA weightings were consistent with the different forearm postures. Under the elbow-bent posture, in contrast, the VPA weightings were significantly higher than the ISO weightings at frequencies ranging from 20 to 80 Hz ($p<0.01$). These results were consistently observed, regardless of the forearm postures. The VPA weightings followed the ISO weighting well in the entire frequency range (Figure 2).

4. DISCUSSION

VPA-based frequency weightings were affected by elbow postures, compared to the effect of forearm postures. Particularly at frequencies up to 80 Hz, where the weighting factors are relatively sensitive to calculation of weighted acceleration values, VPA weightings were significantly higher under elbow-bent postures and were significantly lower under elbow-stretched postures. Based on the analogy of the VPA weightings to ISO weightings (Dong et al., 2006), vibration dose of workers operating vibrating tools with their elbow relatively stretched might be overestimated. In contrast, workers operating vibrating tools with their elbow bent might have vibration exposure more than that evaluated according to the ISO-weighted acceleration. Epidemiological study will be needed to validate our results from the medical aspect.

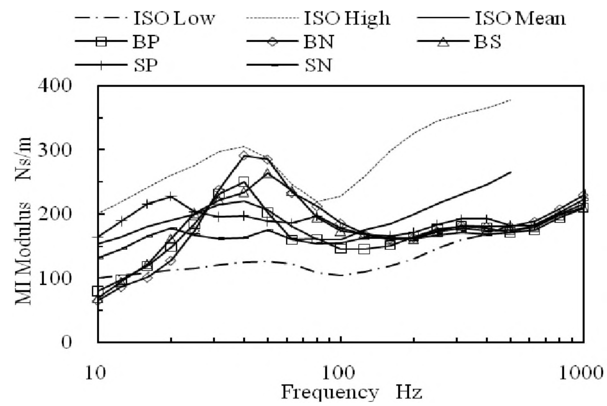

Figure 1. MI modulus under various arm posture.

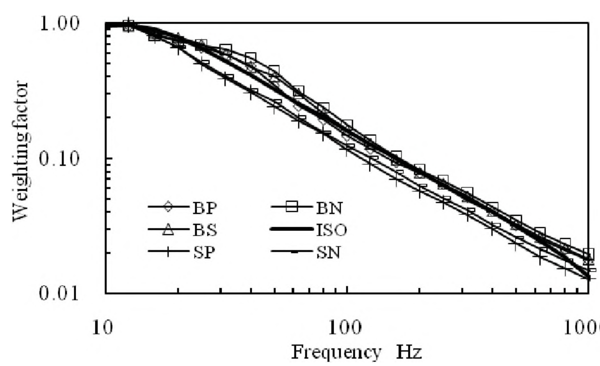

Figure 2. VPA-based frequency weightings.

REFERENCES

ISO 5349-1 (2001). *Mechanical Vibration - Measurement and Evaluation of Human Exposure to Hand-Transmitted Vibration-Part I: General Requirements* (International Organization for Standardization, Geneva).

Dong, R.G., Welcome, D.E., McDowell, T.W., Wu, J.Z., and Schopper, A.W. (2006). "Frequency weighting derived from power absorption of fingers-hand-arm system under z_h-axis vibration," J. Biomech., **39**, 2311-2324.