EVALUATION OF GENDER DIFFERENCES IN FOOT-TRANSMITTED VIBRATION

Pulkit Singh[1], Tammy Eger[1], Jim Dickey[2], Ron House[3], and Michele Oliver[4]
[1]School of Human Kinetics, Laurentian University, Sudbury, ON, Canada, P3E 2C6
[2]School of Kinesiology, University of Western Ontario, London, Ontario, Canada
[3]Dept. of Occup. and Environ. Medicine, St. Michael's Hospital, Toronto, ON, Canada, M5B 1WB
[4]School of Engineering, University of Guelph, Guelph, Ontario, Canada, N1G 2W1

1. INTRODUCTION

Vibration can enter the body of mobile equipment operators, the hands of workers using power-tools or the feet of workers standing on vibrating platforms (Eger et al., 2006). There has been extensive research on adverse health effects resulting from exposure to vibration when seated or when gripping power-tools. However, research associated with vibration exposure via the feet is limited.

Prolonged vibration exposure at the feet can lead to neurological, vascular and musculoskeletal symptoms occurring either due to direct segmental exposure of the feet to vibration (Thompson et al. 2010;), or as a secondary complication to hand-arm vibration syndrome through sympathetic activation (Sakakibara and Yamada 1995).

Despite evidence of vibration induced white-feet, there is limited research on the biodynamic response of the foot to vibration exposure. Investigating the biodynamic response of the human body to vibration is necessary to understand how vibration influences human comfort, performance and health. Understanding the biodynamic response of the foot is also required to select protective equipment that could help to attenuate foot-transmitted vibration. Therefore, the purpose of this study is to measure vibration transmissibility via the feet in individuals exposed to vibration while standing, and to determine if transmissibility and subjective reports of discomfort differed between males and females.

2. METHODS

Vibration transmissibility through the foot was measured while participants stood on a vibration platform. The Laurentian University research ethics board approved all experimental procedures.

2.1. Participants

Ten healthy participants of university age (five males; five females) were recruited from a sample of convenience, and were ruled out for a history of lower body musculoskeletal injury in the last 6 months, vasculopathy, neuropathy, motion sickness, diabetes or history of head injury. All participants were informed of the nature of the experiment and written informed consent was obtained prior to data collection.

2.2. Vibration Exposure

Participants were exposed to a 31.5 Hz dominant frequency vibration with an average frequency-weighted RMS acceleration between 7-13 m/s^2 via a vibration exercise platform (Power Plate North American, Inc., Irvine, CA). This vibration frequency was selected to simulate the vibration experienced when standing on drilling platforms and raises used in underground mining (Leduc, 2011). Participants were asked to stand on the platform, with socked feet, for two 30-second exposure trials with 20 seconds of rest between trials. Participants were also asked to give a verbal discomfort report, after each trial, using a 9-point discomfort scale and a body chart to indicate regions of discomfort.

2.3. Vibration Measurement

Vibration data were collected in accordance with the ISO 2631-1 standard for whole body vibration. Two S2-10G-MF tri-axial accelerometers (NexGen Ergonomics, Montreal, QC) were used to measure vibration on the floor of the vibration platform and the lateral malleolus of the foot. A DataLOG II P3X8 (Biometrics, Gwent, UK) data logger was used to record the vibration data. Participants stood on a standard rubber pad with a tri-axial accelerometer in order to measure platform vibration, and a second accelerometer was secured to the medial malleolus with medical adhesive tape and athletic wrap.

2.4. Data Analysis

Vibration Analysis Toolset (NexGen Ergonomics, Montreal, QC) was used to calculate the frequency-weighted vibration at the floor and the ankle in accordance with ISO 2631-1.

Frequency-weighted acceleration in the z-axis entering the foot (Fa_{wz}) was compared to frequency-weighted acceleration in the z-axis at the ankle (Aa_{wz}). The percent different between $Aa_{wz,}$ and Fa_{wz} is presented as a crude measure of vibration transmissibility from the floor through the foot to the ankle. Values greater than 100% are indicative of vibration amplification between the floor and the ankle while values less than 100% are indicative of vibration attenuation.

3. RESULTS AND DISCUSSION

Vibration measured at the floor and the ankle and percent difference in z-axis vibration between ankle and floor expressed as a percentage is summarized in Table 1. Measured z-axis vibration was lower at the ankle in all trials with the exception of one male. Thus, it can be hypothesized that anatomical structures of the foot, for example the heel fat pad, could play a role in attenuation of foot-transmitted vibration from the floor through the foot to the ankle.

Vibration transmissibility to the ankle was significantly lower for females than males. This finding is in line with Lundstrom et al., 1998 who reported females tend to absorb more vibration power per kilogram due to higher body fat to muscle mass ratio. Therefore, it could be hypothesized that differences in transmissibility between genders could be the result of difference in the foot architecture in terms of arch type and bony structure. Participants reported whole body, face; neck, upper back, abdomen, thigh, knee, lower leg, ankle, and feet discomfort (Table 1). Several participants also reported tingling of ear and itchiness in the nose and legs.

Table 1. Vibration recorded at the floor and ankle, with % difference and subjective reports of discomfort.

Gender	Mass (lbs)	Floor Faw_z (ms^{-2})	Ankle Aaw_z (ms^{-2})	Percent Difference Aa_{wz}/Fa_{wz} (%)	Discomfort by Body Region* Score 0-9 (9 = max. discomfort)
Male	165	9.4	3.1	32.8	WB=3
Male	184	7.5	9.5	126.7	F=1; T=3; K=3
		8.6	8.1	94.3	T=3; F=3
Male	135	11.8	8.2	69.0	H=7; N=7; K=7; F=7; A=7
		12.2	8.1	66.5	H=8; N=8; K=8; Ft=8; A=8
Male	150	9.3	3.1	33.5	K=9; F=9
		10.1	3.0	29.5	T=9; F=9
Male	160	10.6	7.1	66.7	K=3
		9.8	8.1	82.4	WB= 2
Female	120	11.5	7.1	61.7	WB= 3
		11.4	7.2	63.0	WB= 4
Female	180	9.4	3.5	37.6	F=1
		8.9	3.2	36.0	no discomfort
Female	125	11.6	6.7	98.0	F=7; H=7; LL=2
		12.6	7.8	61.9	LL=4; UB=4
Female	130	11.1	2.5	22.6	H=1; LL=1
		12.8	2.1	16.3	H=1; LL=1
Female	140	10.9	5.5	50.5	F=6; LL=6; Ft=5
		10.8	3.0	27.4	H=8; Ab=3; Ft=6

* WB=whole body; F=face; N=neck; UB=upper back; Ab=abdomen; T=thigh; K=knee; LL=lower leg; A=ankle; Ft=feet

4. CONCLUSIONS

The percent difference in z-axis vibration measured between the ankle and the foot was significantly lower for female participants than male participants suggesting females attenuate foot-transmitted vibration more effectively than males. Future research should evaluate the biodynamic response of the foot to foot-transmitted vibration under a larger range of exposure frequencies. Vibration transmissibility should also be measured at more locations across the foot, and the role of arch type, surface area in contact with the vibration surface, and center of pressure while standing should all be considered in future studies.

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