EVALUATION OF TRANSMISSIBILITY PROPERTIES OF ANTI-FATIGUE MATS USED BY WORKERS EXPOSED TO FOOT-TRANSMITTED VIBRATION

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1. INTRODUCTION

Miners can be exposed to foot-transmitted vibration when operating locomotives, bolters, jumbo drills and/or drills attached to platforms workers also stand on. Case reports suggest miners are reporting pain, discomfort and blanching in the toes more often than their co-workers who are not exposed to vibration via the feet (Choy et al., 2008; Thompson et al., 2010). A recent field study reported considerable differences in the dominant frequency associated with locomotive operation (3.15–6.3 Hz) compared to drilling or 'bolting off' from platforms (31.5-40 Hz) (Leduc et al., 2010), suggesting a rationale for greater reports of vibration-induced white feet in workers with a history of exposure to higher frequency vibration at the feet. Although little is known about the resonant frequency of the foot, researchers have suggested the hands and fingers are at a greater risk of injury when exposed to frequencies in the range of 20-25 Hz, and greater than 100Hz, respectively (Dong et al., 2004). Given the anatomical similarity between structures of the feet and the hand, it is reasonable to hypothesize that workers exposed to frequencies in this range could be more susceptible to vibration-induced white feet.

In order to decrease injury risk, engineering controls could be used to decrease vibration exposure at the source, administration controls could be used to decrease a workers daily exposure, and/or personal protective equipment could be used to attenuate vibration before it enters the feet of the workers. Engineering controls would be ideal and several mining companies are working to reduce vibration produced by drills, and manufacturers are working on new platforms designed to isolate the worker from vibration; however, these changes will take time and workers continue to report health problems associated with vibration exposure at the feet. The use of mats to attenuate vibration at the feet has been suggested as a possible intervention. However, controlled studies have yet to evaluate the effectiveness of mats in attenuating vibration. Therefore, the purpose of this study was to evaluate the transmissibility properties of three commercially available “anti-fatigue” mats currently used on equipment operated in underground mines in Ontario, Canada.

2. METHODS

All procedures were approved by the Laurentian University Research Ethics Board and informed consent was provided.

2.1. Participants

Ten participants, with no history of lower body musculoskeletal injury, head injury, diabetes, vasculopathy, or neuropathy participated in this study.

2.2. Experimental Design

A four mat (M1; M2; M3; NM) by two vibration exposure profile (VP1; VP2) experimental design with one repeat was carried out. The order of mats tested was randomized within each vibration exposure block and the order of vibration exposure profile was also randomized. Participants were exposed to foot-transmitted vibration for 20 seconds while standing on each mat with 10 seconds of rest between mat conditions.

2.3. Vibration Exposure

VP1 was generated by a custom-built whole-body vibration simulator while VP2 was generated by a vibration exercise platform (Power Plate North American, Inc., Irvine, CA). VP1 had a dominate frequency between 3-5 Hz with a frequency-weighted RMS acceleration ranging between 1-5.5 m/s^2, while VP2 had a dominant frequency between 30-31.5 Hz with frequency weighted RMS acceleration ranging between 8-12.5 m/s^2. The vibration profile frequencies were selected to simulate the dominant vibration frequency experienced when operating a locomotive and drilling from a raised platform, respectively (Leduc et al., 2010).

2.4. Vibration Measurement

Vibration data were collected in accordance with ISO 2631-1:1997. Two S2-10G-MF tri-axial accelerometers (NexGen Ergonomics, Montreal, QC) were used to measure vibration on the floor of the vibration platform and on the surface of the mat. The accelerometers were aligned and positioned directed underneath the right foot of the standing participant. A DataLOG II P3X8 (Biometrics, Gwent, UK) data logger was used to record the vibration data. Participants stood on a standard rubber pad with an embedded tri-axial accelerometer in order to measure vibration on top of the mat.

2.5. Data Analysis

Vibration Analysis Toolset v. 5.0 (NexGen Ergonomics, Montreal, QC) was used to calculate the frequency-weighted vibration at the floor and above the mat in accordance with ISO 2631-1:1997 and ISO 5349-1:2001. A mat effective amplitude transmissibility (MEAT) value was calculated as a percent ratio between frequency-weighted acceleration in the z-axis on the mat (Ma_{wz}) to frequency-weighted acceleration in the z-axis on the floor (Fa_{wz}). A MEAT value greater than 100% indicated vibration was amplified as it travelled through the mat while a value less than 100% suggested the mat attenuated the vibration.

3. RESULTS AND DISCUSSION

The purpose of this study was to determine if any commercially available mats used in underground mines in Ontario were effective at attenuating foot-transmitted vibration. The ISO-2631-1 z-axis MEAT score for M2 was slightly less than 100 % for both vibration exposure profiles and at/slightly above 100% for M1 and M3 (Table 1). When the MEAT score was calculated using ISO 5349-1 weighted z-axis data, only M2 when exposed to higher frequency vibration was below 100%.

Table 1. Mean M.E.A.T. values for mat and vibration conditions determined with frequency weighted acceleration calculated according to ISO 2631-1 and ISO 5349-1.

Mat	Vib. Profile	Mean MEAT Z –axis IS0 2631-1 % (SD)	Mean MEAT Z –axis IS0 5349-1 % (SD)
M1	VP1	103 (6)	107 (12)
M1	VP2	100 (5)	100 (11)
M2	VP1	96 (5)	102 (9)
M2	VP2	99 (2)	99 (6)
M3	VP1	102 (5)	103 (8)
M3	VP2	100 (4)	100 (7)

Vibration-induced white feet has been reported in miners exposed to foot-transmitted vibration with a dominant frequency in the 30-40 Hz range (Thompson et al., 2010; Leduc et al., 2010). Miners who experienced Raynaud's phenomenon in the toes in Hedlund's study (1989) also operated equipment known to expose workers to higher frequency foot-transmitted vibration. Therefore, if a mat is going to be used as an effective piece of personal protective equipment it needs to be able to attenuate higher frequency vibrations. None of the mats tested in the current study showed any meaningful attenuation of vibration at the low frequency (3-5 Hz) or the high frequency (30-31.5 Hz). However, workers might still benefit from standing on the mats when the "anti-fatigue" features of the mats are considered. Anti-fatigue mats are designed to allow the body to sway naturally while standing (King, 2002), leading to small subtle movements of the calf and leg muscles resulting in improved blood flow and reduced fatigue (King, 2002). Positive anecdotal feedback provided by miners in a field study also supports continued use of mats in underground mines (Leduc, 2011). Future research should evaluate mats with a larger range of frequencies in order to replicate better the spectral content present in occupational exposure. Moreover, it is essential to determine if amplification occurs at the frequency range that is linked to potential damage to the feet. Future work should also evaluate mats that have been used over a longer duration. All the mats tested in this study were new and testing was limited to 20 second trials. Future testing should also evaluate mats in the field, particularly since anti-vibration glove testing has revealed that the comparison of field and laboratory results did not produce the same ranking of gloves (Pinto et al., 2001).

4. CONCLUSIONS

The transmissibility of three commercially available anti-fatigue mats were evaluated to determine if any of the mats were capable of attenuating foot-transmitted vibration experienced during underground mining applications. None of the mats produced relevant attenuation.

REFERENCES

Choy, N., Sim C. S., Yoon, J. K., Kim S, H., Park H, O., Lee J, H., and Yoo, C. I. (2008). "A case of Raynaud's Phenomenon of both feet in a rock drill operator with hand-arm vibration syndrome," Korean J. Occup. Environ. Med., **20**(2), 119-126.

Dong, R. G., Schopper, A. W., McDowell, T. W., Welcome, D. E., Wu, J. Z., Smutz, W. P., Warren, C., and Rakheja, S. (2004). "Vibration energy absorption (VEA) in human fingers-hand-arm system," Med. Eng. & Physics, **26**(6), 483-492.

Hedlund, U. (1989). "Raynaud's Phenonmenon of fingers and toes of miners exposed to local and whole-body vibration and cold," Int. Arch. Occup. Environ. Health, **61**, 457-461.

King, P. M. (2002). "A comparison of the effects of floor mats and shoe in-soles on standing fatigue," Appl. Ergon., **33**, 477-484.

Leduc, M., Eger, T., Godwin, A., Dickey, J., and House, R. (2010). "Examination of vibration characteristics for workers exposed to vibration via the feet," *3rd Am. Conf. Human Vibration* (Iowa City Iowa).

Leduc, M. (2011). "Examination of vibration characteristics and transmissibility properties of anti-fatigue mats for workers exposed to vibration via the feet," Masters Thesis, Laurentian University, Sudbury, ON.

Pinto, I., Stacchini, N., Bovenzi, M., Paddan, G. S., and Griffin, M. J. (2001). "Protection effectiveness of anti-vibration gloves: field evaluation and laboratory performance assessment: Appendix H4C to Final Report May 2001," *Proc. 9th Int. Conf. Hand-Arm Vibration* (Nancy, France).

Thompson, A., House, R., Krajnak, K., and Eger, T. (2010). "Vibration white foot: a case report," Occup. Med., **60**, 572-574.

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