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Fingers vibration transmission performance of vibration reducing gloves

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ABSTRACT

Vibration attenuation performance of vibration reducing (VR) gloves is, invariably, measured at the palm using the method described in ISO 10819 (2013). The standardized method, however, does not address the glove performance in terms of fingers vibration, which is substantially different from that of the palm. An investigation was conducted to enhance the understanding of fingers vibration transmission properties of 4 different types of VR gloves (air, gel, hybrid and leather) using 4 male subjects in the laboratory. Three different finger adapters, each containing a miniature three-axis accelerometer, were designed and assessed for measurements of vibration responses at the fingers of the gloved hand. Vibration responses of the VR gloves were measured at the middle phalanges of the index and middle fingers using two Velcro finger adapters under the standardized vibration spectra and the spectra of 3 different hand tools, namely a road breaker, a nutrunner and an orbital sander. Vibration transmissibility of the gloves was also measured at the palm using the standardized palm adapter. The frequency response functions (FRF) obtained for the fingers of the gloved hand were used to estimate vibration transmission performances of the gloves at the index and middle fingers. The results show that only the air and hybrid VR gloves provide some attenuation of vibration transmitted to the index finger compared to the bare hand, while nearly all the gloves amplify vibration of the middle finger. The vibration attenuation was evident at the palm for the air and hybrid gloves above 40 Hz. The gel and leather gloves revealed nearly unity transmissibility in most of the frequency range. Only the hybrid glove passed the criteria of ISO 10819 (2013) to be designated as an anti-vibration (AV) glove, although it amplified vibration transmitted to the middle finger, particularly in the H-frequency range (200–1250 Hz). Fairly good agreements (−11%–13%) were obtained between the measured and estimated fingers vibration responses for all the gloves using the FRF method under the vibration spectra of the selected tools.

*Relevance to industry:*Vibration is transmitted to the hand-arm system of operators using power tools and occupational exposure to hand transmitted vibration (HTV) arising from hand-held power tools has been related to an array of disorders. Vibration reducing (VR) gloves are viewed as one of the simple methods to protect workers from hand-arm vibration syndrome (HAVS). The international standard on the assessment of VR gloves addresses only the transmission of vibration to the palm, even though the vibration responses of fingers are substantially different. This study explored both the palm and fingers vibration transmissibility characteristics of VR gloves and proposed a method for assessing the vibration reduction performance of the glove under vibration spectra of different tools. The results of the study are thus considered to provide guidance towards enhanced screening criteria for AV gloves, and for selection of gloves for different tools.

1. Introduction

Operators of hand-held power tools are exposed to comprehensive levels of hand-transmitted vibration (HTV) arising from tool-hand interactions. Occupational exposure to such vibration

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has been related to an array of disorders in the vascular, sensorineural and musculoskeletal structures of the hand-arm system, collectively defined as the hand-arm vibration syndrome (HAVS) (Gemne and Taylor, 1983). The most serious among the diseases is perhaps the vascular disorder, which has been denoted by several different terms, such as Raynaud's phenomenon of occupational origin, traumatic vasospastic disease and vibration-induced white finger (VWF) (Taylor and Pelmear, 1975). The first symptoms of VWF disease are related to intermittent tingling and numbness of the fingers. Under continued exposure, these are followed by an attack of finger blanching confined, in the first instance, to the fingertips, which subsequently propagates to base of the fingers. The cold also acts as the provocative agent.

A number of studies have suggested that health risks imposed by HTV could be reduced by considering two factors, namely control of HTV and ergonomic interventions. Several technical solutions have been proposed over the years to reduce the vibration exposure levels of vibratory hand tools, but the success to reduce HTV have been limited to only a few hand tools, primarily due to the compact designs of hand tools, the associated cost and possibly the reduced working efficiency. Gloves are the most commonly used protective devices for the human hand in the workplace for protection against mechanical trauma, thermal extremities and vibration. In order to protect workers, different types of vibration reducing (VR) gloves have been developed, assessed and utilized to attenuate the HTV generated by tools (Christ, 1982; Griffin et al., 1982; Goel and Rim, 1987; Rens et al., 1987).

The International Organization for Standardization (ISO) has described a measurement procedure for assessing vibration transmission performance of a glove using a palm adapter equipped with a miniature accelerometer (ISO 10819 2013). The standardized method assesses the effectiveness of VR gloves solely on the basis of vibration transmitted to the palm. Vibration transmissibility of different gloves to the palm of the hand have been investigated in many studies (Hewitt, 1998; Pinto et al., 2001; Dong et al., 2002, 2004; Rakheja et al., 2002; Reynolds and Wolf, 2005; Welcome et al., 2012; McDowell et al., 2013). The ISO 10819 (2013) standard also defines the screening criteria for a glove to be classified as an anti-vibration (AV) glove. According to this standard, an AV glove must have a frequency-weighted palm acceleration transmissibility $\leq$0.9 in the medium frequency range (25–200 Hz) and $\leq$0.6 in the high frequency range (200–1250 Hz). The standard also requires that an AV glove employ the same vibration reducing materials in the palm and fingers regions, while the thickness of the vibration reducing material placed in the fingers and the thumb regions shall be $\geq$ 60% of the thickness of the material placed in the palm region. However, the reasoning for using the same vibration reducing materials at the palm and fingers is not sufficiently justified. The standard likely assumes similar vibration transmission performance of the glove material at the palm and the fingers, although the dynamic responses of the fingers differ greatly from that of the palm of the hand (Dong et al., 2012). The vibration isolation effectiveness of a glove depends not only on the mechanical properties of the vibration reducing materials, but also on the masses and dynamics of the fingers and the palm. The tissues of the fingers and the palm absorb vibration, while the effective fingers tissue mass is considerably small as compared to the palm tissue mass. Furthermore, the resonant frequencies and the hand-handle contact force distributed at the fingers are substantially different from those of the palm of the hand (Aldien et al., 2005; Dong et al., 2007). The nature of vibration transmitted through the glove material to the palm and the fingers are thus expected to differ. Glove is theoretically more effective to attenuate HTV at the palm along the forearm direction as compared to the fingers (Dong et al., 2012). A number of studies have reported doubts on the methodology evaluating VR gloves at the palm only (ISO 10819, 1996) and on the usefulness of VR gloves for attenuating finger vibration (Griffin, 1990, 1998; Paddan and Griffin, 2001; Dong et al., 2009).

The measurement of vibration transmitted to the fingers of a gloved hand, however, poses complex challenges. Only a few studies have thus attempted to measure the effectiveness of VR gloves in reducing vibration transmitted to the fingers (Griffin et al., 1982; Paddan and Griffin, 2001; Welcome et al., 2014). Welcome et al. (2014) used a 3-D scanning laser vibrometer to measure vibration transmitted to the fingers with and without wearing VR gloves (gel and air bladder). The study reported that the gloves yield only little vibration reduction at the fingers at frequencies below 80 Hz (less than 3%) with notable amplification in the 80–400 Hz range. The gel glove was found to be more effective in reducing vibration at the fingers at higher frequencies as compared with the air bladder glove.

The assessments of the vibration reduction performance of VR gloves as specified by the standardized method (ISO 10819, 2013) are conducted under an idealized vibration spectrum in the 25–1250 Hz frequency range. The vibration spectra of hand held power tools, however, invariably differ from the standardized spectra. Griffin et al. (1998) measured vibration transmissibility of 10 different gloves for predicting the isolation effectiveness of gloves under vibration spectra of 20 different hand tools. The study concluded that the standardized tool spectra cannot predict the vibration isolation performance of VR gloves coupled with different tools. On the basis of the frequency response characteristics of the gloves, Rakheja et al. (2002) proposed a methodology to estimate the vibration isolation effectiveness of AV gloves as a function of handle vibration of specific tools. The effectiveness of the method was demonstrated through comparisons of estimated vibration transmissibility of 2 different gloves with the mean measured responses obtained for different tools' spectra. Dong et al. (2014) estimated tool specific vibration reduction characteristics of four different VR gloves to the palm of the hand in three orthogonal directions (3-D), based on the frequency-weighted vibrations transmitted to the palm of the hand. The study concluded that the VR gloves offer only minimal vibration reduction (<5%) at low frequencies (<25 Hz) or may even marginally amplify vibration (<10%) at low frequencies. The VR gloves, however, revealed 5–58% reduction in the handle vibration transmitted to the palm of the hand, depending upon the vibration spectra of the different tools.

The present study focuses on the assessment of the effectiveness of VR gloves in view of vibration transmitted to both the palm and the fingers under the standardized as well as different tools' vibration spectra. Different designs of adapters were assessed for repeatable and reliable measurements of finger vibration. Vibration transmission characteristics of 4 different VR gloves were measured at the middle phalanges of the index and middle fingers using the finger adapters under the standardized and 3 different hand tools (road breaker, nutrunner and orbital sander) vibration spectra. Vibration transmission characteristics of the VR gloves were also measured at the palm using the standardized palm adapter. The frequency response functions (FRF) for both the fingers and the palm were used to assess the performance of the VR gloves in reducing vibration transmitted to the palm and the fingers. The FRFs were also used to estimate the vibration transmission performance of the VR gloves under the selected tools vibration spectra.

2. Methods

2.1. Experimental setup

Fig. 1 illustrates the experimental setup for the measurement of