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The effects of vibration-reducing gloves on finger vibration

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A B S T R A C T

Vibration-reducing (VR) gloves have been used to reduce the hand-transmitted vibration exposures from machines and powered hand tools but their effectiveness remains unclear, especially for finger protection. The objectives of this study are to determine whether VR gloves can attenuate the vibration transmitted to the fingers and to enhance the understanding of the mechanisms of how these gloves work. Seven adult male subjects participated in the experiment. The fixed factors evaluated include hand force (four levels), glove condition (gel-filled, air bladder, no gloves), and location of the finger vibration measurement. A 3-D laser vibrometer was used to measure the vibrations on the fingers with and without wearing a glove on a 3-D hand-arm vibration test system. This study finds that the effect of VR gloves on the finger vibration depends on not only the gloves but also their influence on the distribution of the finger contact stiffness and the grip effort. As a result, the gloves increase the vibration in the fingertip area but marginally reduce the vibration in the proximal area at some frequencies below 100 Hz. On average, the gloves reduce the vibration of the entire fingers by less than 3% at frequencies below 80 Hz but increase at frequencies from 80 to 400 Hz. At higher frequencies, the gel-filled glove is more effective at reducing the finger vibration than the air bladder-filled glove. The implications of these findings are discussed.

Relevance to industry: Prolonged, intensive exposure to hand-transmitted vibration can cause hand-arm vibration syndrome. Vibration-reducing gloves have been used as an alternative approach to reduce the vibration exposure. However, their effectiveness for reducing finger-transmitted vibrations remains unclear. This study enhanced the understanding of the glove effects on finger vibration and provided useful information on the effectiveness of typical VR gloves at reducing the vibration transmitted to the fingers. The new results and knowledge can be used to help select appropriate gloves for the operations of powered hand tools, to help perform risk assessment of the vibration exposure, and to help design better VR gloves.

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1. Introduction

Prolonged, intensive exposure to hand-transmitted vibration is associated with hand-arm vibration syndrome (HAVS). Some vibration-reducing gloves have been developed and applied to attenuate the vibration transmitted to the hand-arm system (Rens et al., 1987; Goel and Rim, 1987; Reynolds and Jetzer, 1998). The International Organization for Standardization (ISO) has set forth a standard for the testing and assessment of such gloves (ISO 10819, 1996). While a few studies reported that some of these gloves could be helpful (Brown, 1990; Jetzer et al., 2003; Mahbub et al., 2007), there is some doubt as to their usefulness for attenuating the vibration transmitted to the fingers (Griffin 1990; 1998; Paddan and Griffin, 2001; Dong et al., 2009). Also as a major concern, these gloves can substantially reduce the finger dexterity and increase handgrip effort (Wimer et al., 2010). As a result, some VR gloves may not be comfortable to wear and may cause hand fatigue. In the worst case, they could become one of the factors resulting in hand injuries due to overexertion or the cause of safety concerns such as loss of dexterity. Although wearing a glove when operating a tool is generally recommended for many good reasons, a VR glove may not be the best choice if its benefits from vibration reduction do not outweigh its adverse effects. The balance is likely to be tool-specific and working condition- or task-specific. To help determine the balance, it is important to find how much vibration the gloves can reduce. While many studies have investigated the vibration

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transmissibility of these gloves at the palm of the hand, the current study focused the examination on the glove transmissibility at the fingers.

Because vibration-induced finger injuries and disorders are the major components of HAVS (Griffin, 1990), the fingers are critical substructures in the hand-arm system. The assessment of VR gloves should be partially based on the level of vibration reduction at the fingers. Largely because of technical challenges, the study of the vibration transmissibility of the VR gloves at the fingers has been very limited (Griffin et al., 1982; Paddan and Griffin, 2001). Probably for the same reason, the standardized anti-vibration glove test is based on the vibration transmissibility of the glove at the palm of a hand along the forearm direction (ISO 10819, 1996, 2013) rather than that at the fingers. However, this standard does indirectly attempt to address the issue of finger vibration attenuation. This is reflected by one of the three criteria for defining anti-vibration gloves. This criterion requires that any anti-vibration glove must be a full-finger glove with the same materials and thickness at the palm and the fingers in the original standard (ISO 10819, 1996). The primary assumption is that if the palm and fingers are covered as per the specification, the glove can similarly reduce vibration transmitted to the palm and fingers; at least, such a glove should be better at attenuating the finger vibration than one that does not meet this criterion. While this assumption has not been sufficiently proven and is questionable, this criterion has a practical problem: the anti-vibration gloves that meet it are usually too bulky to wear. As a result, no glove manufacturer has actually fully implemented this criterion, although some gloves available on the market have been certified as anti-vibration gloves. To allow these gloves to fully comply with the criterion, the requirement in the revised version of the standard has been revised (ISO 10819, 2013); specifically, the thickness of the glove fingers has been relaxed from 100% to $\geq$55% of that at the palm of the glove. Obviously, this revision is not based on the finger vibration attenuation of the gloves but it simply accommodates reality.

Vibration-reducing gloves basically serve as a passive cushion between a hand and a tool at their interface to reduce the transmitted vibration, similar to the function of a suspension system (Dong et al., 2009). Like any passive suspension system, the vibration isolation effectiveness of the glove depends not only on the glove dynamic properties but also on the effective mass of the glove-hand-arm system. Because the effective mass distributed at the palm along the forearm direction is generally the highest for a given exposure condition, the glove is theoretically most effective at reducing the vibration transmitted to the palm in that direction (Dong et al., 2012). This means that the transmissibility measured with the standardized test method generally represents the best case for the vibration reduction capabilities of the glove, as confirmed in a recent study (McDowell et al., 2013). Its effectiveness could be overestimated if this transmissibility value is used for the assessment. Because the effective mass of each finger is small in comparison to that of the palm, the glove is likely only capable of minimal attenuation at the fingers, especially at the fingertips. Once the vibration transmissibility of the gloves at the fingers is reliably measured, the overall effectiveness of the glove for vibration attenuation can be better estimated.

One of the methods to measure the vibration transmissibility of the glove fingers is to insert a finger adapter equipped with a miniature tri-axial accelerometer between the fingers and the glove material, similar to the palm-adapter method used in the standardized glove test (ISO 10819, 1996, 2013). Because the mass and dimensions of each finger are relatively small, compared with the possible mass and dimensions of the finger adapter, the finger adapter equipped with a conventional miniature accelerometer could change the original coupling relationship; as a result, the measured transmissibility may not be sufficiently representative of the actual transmissibility of the glove fingers. Furthermore, the finger vibration transmissibility could vary greatly at different locations on each finger (Welcome et al., 2011). Therefore it is difficult to use the finger adapter method to reliably measure the transmissibility distribution.

Alternatively, the glove finger transmissibility can be indirectly estimated by measuring the vibrations on the fingers with and without wearing the anti-vibration gloves (Griffin et al., 1982; Cheng et al., 1999; Paddan and Griffin, 2001). A modeling study demonstrated that the transmissibility estimated using this relative method is acceptable to approximately represent that at the glove–finger interface (Dong et al., 2009). The major concern of this on-the-finger method is similar to that of the adapter method: the mass of the accelerometer and its fixture may significantly affect the finger vibration. In addition, the installation of the accelerometer on a finger may also apply some artificial constraints to the finger and interact with and influence its dynamic properties, which may also render the measurement unreliable. These problems can be avoided by using a laser vibrometer in the measurement. While the use of a single-direction laser vibrometer for the measurement of hand vibration transmission has been reported by several researchers (Sörensson and Lundström, 1992; Rossi and Tomasini, 1995; Nataletti et al., 2005; Scalise et al., 2007; Concettoni and Griffin, 2009; Xu et al., 2011), a 3-D vibrometer has also been recently used to measure the vibration transmitted to the hand-arm system (Welcome et al., 2011). This technique has made it possible to conduct reliable 3-D measurement of the finger vibration for examining the effectiveness of the gloves for finger vibration exposure protection.

Based on these backgrounds, the objectives of this study are to determine whether the anti-vibration gloves defined by the criteria in the new version of the ISO standard (ISO 10819, 2013) can reduce the vibration transmitted to the fingers and to enhance the understanding of the mechanisms of these gloves. Specifically, the vibration transmissibility spectra of the human fingers with and without wearing a glove were measured in three orthogonal directions using a 3-D laser vibrometer on a 3-D hand-arm vibration test system. Two typical vibration-reducing glove types are considered in the experiment under several different grip forces. The experimental results are used to evaluate the effectiveness of these gloves for reducing the vibration transmitted to the fingers. To help understand the mechanisms of the glove effects, the role of the grip force in the finger transmissibility is also examined.

2. Methods

2.1. Instrumentation

Fig. 1 shows a layout of the basic instrumentation and the subject posture used in this study. Fig. 2 shows a pictorial view of the experimental setup. A 3-D vibration test system (MB Dynamics, 3-D Hand-Arm Vibration Test System) was employed to generate the required vibration spectrum in each of the three directions: Z_h is along the forearm; Y_h is along the centerline of the instrumented handle in the vertical direction; and X_h is the direction normal to the Y_h–Z_h plane. An instrumented handle equipped with a tri-axial accelerometer (Endevco, 65-100) and a pair of force sensors (Interface, SML-50) were used to measure the 3-D accelerations and applied grip force. To assure a good signal, a retro-reflective tape was wrapped on the handle. A force plate (Kistler 9286AA) was used to measure the push force applied to the handle. The applied grip and push forces were displayed on two virtual dial gages on a computer monitor in front of the subject, as also shown in Fig. 1. A 3-D scanning laser vibrometer (Polytec, 3-D PSV-400)