International Journal of Industrial Ergonomics 44 (2014) 827–839

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Tool-specific performance of vibration-reducing gloves for attenuating palm-transmitted vibrations in three orthogonal directions

Ren G. Dong [a,*], Daniel E. Welcome [a], Donald R. Peterson [b], Xueyan S. Xu [a], Thomas W. McDowell [a], Christopher Warren [a], Takafumi Asaki [b], Simon Kudernatsch [b], Antony Brammer [b]

[a] Engineering & Control Technology Branch, National Institute for Occupational Safety and Health, Morgantown, WV 26505, USA
[b] Biodynamics Laboratory, University of Connecticut Health Center, Farmington, CT 06030-2017, USA

ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form
9 September 2014
Accepted 21 September 2014
Available online 11 October 2014

Keywords:
Anti-vibration glove
Vibration-reducing glove
Hand-arm vibration
Hand-transmitted vibration
Hand-arm vibration syndrome

ABSTRACT

Vibration-reducing (VR) gloves have been increasingly used to help reduce vibration exposure, but it remains unclear how effective these gloves are. The purpose of this study was to estimate tool-specific performances of VR gloves for reducing the vibrations transmitted to the palm of the hand in three orthogonal directions (3-D) in an attempt to assess glove effectiveness and aid in the appropriate selection of these gloves. Four typical VR gloves were considered in this study, two of which can be classified as anti-vibration (AV) gloves according to the current AV glove test standard. The average transmissibility spectrum of each glove in each direction was synthesized based on spectra measured in this study and other spectra collected from reported studies. More than seventy vibration spectra of various tools or machines were considered in the estimations, which were also measured in this study or collected from reported studies. The glove performance assessments were based on the percent reduction of frequency-weighted acceleration as is required in the current standard for assessing the risk of vibration exposures. The estimated tool-specific vibration reductions of the gloves indicate that the VR gloves could slightly reduce (<5%) or marginally amplify (<10%) the vibrations generated from low-frequency (<25 Hz) tools or those vibrating primarily along the axis of the tool handle. With other tools, the VR gloves could reduce palm-transmitted vibrations in the range of 5%–58%, primarily depending on the specific tool and its vibration spectra in the three directions. The two AV gloves were not more effective than the other gloves with some of the tools considered in this study. The implications of the results are discussed.

Relevance to industry: Hand-transmitted vibration exposure may cause hand-arm vibration syndrome. Vibration-reducing gloves are considered as an alternative approach to reduce the vibration exposure. This study provides useful information on the effectiveness of the gloves when used with many tools for reducing the vibration transmitted to the palm in three directions. The results can aid in the appropriate selection and use of these gloves.

1. Introduction

Prolonged, intensive exposure to hand-transmitted vibration may cause hand-arm vibration syndrome (HAVS) (Griffin, 1990; NIOSH, 1997). To help reduce such exposures, vibration-reducing (VR) gloves have been designed not only to provide typical work glove functions, but also to isolate some vibrations transmitted to the hand-arm system (Rens et al., 1987; Goel and Rim, 1987; Reynolds and Jetzer, 1998; Jetzer et al., 2003). In principle, the vibration isolation effectiveness of a glove depends primarily on the dynamic properties of both the glove and hand-arm system (Dong et al., 2009); any factor affecting their properties may also influence glove effectiveness. It is difficult to judge these gloves without specifying their application conditions. Furthermore, the performances of available commercial VR gloves may vary significantly. To help select appropriate gloves, the International Organization for Standardization (ISO) has set forth a testing method and a set of criteria to classify anti-vibration (AV) gloves (ISO 10819, 1996, 2013). In other words, AV gloves are a subset of VR gloves; they

* Corresponding author. ECTB/HELD/NIOSH/CDC, 1095 Willowdale Road, MS L-2027, Morgantown, WV 26505, USA. Tel.: +1 304 285 6332; fax: +1 304 285 6265.
E-mail addresses: rkd6@cdc.gov, RDong@cdc.gov (R.G. Dong).

http://dx.doi.org/10.1016/j.ergon.2014.09.007
0169-8141/Published by Elsevier B.V.

are supposed to reduce more vibration transmitted to the hand than VR gloves that do not fully meet the criteria. Specifically, this test method requires measuring the glove vibration transmissibility of frequency-weighted acceleration at the palm of the hand along the forearm direction with a specified hand and arm posture while forces of 30 N grip and 50 N push are applied to a vibrating 40 mm cylindrical handle. According to the latest version of the standard (ISO 10819, 2013), the glove can be classified as an AV glove if it meets the following three criteria: (i) the transmissibility value in the middle-frequency range (25–200 Hz) is less than or equal to 0.90; (ii) the transmissibility value in the high-frequency range (200–1250 Hz) is less than or equal to 0.60; and (iii) the glove is full fingered; the materials of the glove fingers are the same as those of glove palm; and the thickness of the glove fingers is more than 0.55 times that at the palm of glove.

Whereas the AV glove criteria basically constitute a pass/fail test, the required reductions do not generally represent actual vibration reductions of these gloves when used with specific tools. This is primarily for the following reasons:

a) The vibration attenuation effectiveness of a glove is tool vibration-specific (Griffin, 1998; Rakheja et al., 2002; Dong et al., 2002a). No powered hand tool generates the idealized vibration spectrum required in the standardized glove test (ISO 10819, 1996, 2013); as a result, the transmissibility values measured with the standard method are not directly applicable to any specific tool.
b) The glove effectiveness is direction-specific (Hewitt, 2010; McDowell et al., 2013a). This is because the dynamic properties of the glove materials and the driving-point biodynamic responses may vary with direction (Dong et al., 2013). As abovementioned, the standardized glove test prescribes that glove vibration transmissibility be measured only in the forearm direction.
c) The glove effectiveness is also location-specific because the glove properties and the distribution of hand apparent mass generally vary with the locations of the glove and hand (Dong et al., 2009, 2013). This is also clearly reflected by the large differences between the vibration transmissibility spectrum of the glove measured at the palm and that measured at the fingers (McDowell et al., 2013a; Welcome et al., 2014). Tool-specific glove performances at the palm and fingers should also be examined separately.

While the standard glove test is primarily intended to screen gloves (ISO 10819, 1996, 2013), the tool-specific vibration isolation performances of gloves have to be determined using other methods. Intuitively, the vibration transmissibility of a glove can be measured during tool operations at workplaces. Because many factors may affect glove vibration transmissibility, it is usually difficult and expensive to reliably assess glove effectiveness at workplaces, as substantial variations among measurement data have been observed (Pinto et al., 2001). Probably for these reasons, only a few studies have used the direct measurement approach to investigate tool-specific vibration isolation effectiveness of gloves (Goel and Rim, 1987; Cheng et al., 1999; Pinto et al., 2001; Dong et al., 2002a, 2003).

As an alternative method, tool-specific performances of gloves can be estimated using the vibration transmissibility spectra measured in laboratory tests over a sufficiently broad frequency band and with tool vibration spectra measured at workplaces. This approach avoids the difficulties of direct measurement and takes advantage of the available experimental data. It is recommended as an optional method for estimating tool-specific vibration transmissibility in the glove test standard (ISO 10819, 1996, 2013). Several studies evaluated this transfer function method (Rakheja et al., 2002; Dong et al., 2002a; Welcome et al., 2012). Those studies demonstrated that VR glove transmissibility is largely independent of the vibration exposure spectrum. This has led to the replacement of the two excitation spectra used in the original glove test standard (ISO 10819, 1996) with a single excitation spectrum required in the revised test standard (ISO 10819, 2013). This also suggests that it is reasonable to approximate tool-specific glove performances using the transmissibility spectrum of a glove measured in the laboratory. However, the current literature contains only a few reports of tool-specific glove vibration transmissibility values along the forearm direction at the palm of the hand (Rakheja et al., 2002; Dong et al., 2002a). Further studies are required to estimate the tool-specific performances of gloves in multi-axial vibration exposures.

Many tool vibration spectra can be found in the literature. Several studies reported the vibration transmissibility spectra of some typical VR gloves at the palm of the hand along the forearm direction (Dong et al., 2002a, 2002b, 2003, 2004, 2009, Welcome et al., 2011, 2012). A recent study also reported their spectra in three orthogonal directions (3-D) (McDowell et al., 2013a). These experimental data have made it possible to estimate the tool-specific effectiveness of typical VR gloves at the palm of the hand in three orthogonal directions. Therefore, the specific aims of this study are to measure additional glove transmissibility spectra and tool vibration spectra for verifying and enhancing the database for such estimations, to synthesize the representative glove spectra using the available data, and to estimate the tool-specific effectiveness of VR gloves at the palm of the hand. The measured spectra, together with archived data, are also used to further verify the most important assumption of this study: the vibration transmissibility spectrum of a glove is largely independent of the excitation conditions. Based on the estimated vibration reductions provided by the gloves, the appropriate selection and use of VR gloves for various vibrating tools or machines are discussed.

2. Methods

2.1. Vibration transmissibility spectra of gloves at the palm of the hand

2.1.1. Available 3-D transmissibility spectra

McDowell et al. (2013a) reported 3-D transmissibility spectra of six VR gloves and one regular work glove. The 3-D spectra were simultaneously measured on a 3-D vibration test system using a palm adapter method with hand and arm postures similar to those required in the standardized glove test (ISO 10819, 1996, 2013). The basic trends and characteristics of the spectra are consistent with those predicted using a model of the glove-hand-arm system (Dong et al., 2013). These data were considered as part of the basis for synthesizing the transmissibility spectra. Specifically, three air bladder-filled gloves were tested in the reported study (McDowell et al., 2013a). Because these air bladder gloves exhibited similar 3-D transmissibility spectra, only one of them was considered in the current study. The regular work glove did not significantly isolate vibration; thus, that glove was not considered further in the current study. The three remaining VR gloves were manufactured from different materials and had some significant differences among their transmissibility spectra; they were included in the current study. The four VR gloves considered in this study are shown in Fig. 1. Their basic features are listed in Table 1.

Fig. 2 shows the basic test setups used in the measurement by McDowell et al. (2013a). The hand and arm postures used in the study are similar to those required in the standard glove test (ISO 10819, 1996, 2013). Seven adult males participated in the measurement with three hand force treatments (15 N grip + 30 N push,