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# Fingers' vibration transmission and grip strength preservation performance of vibration reducing gloves

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ABSTRACT

The vibration isolation performances of vibration reducing (VR) gloves are invariably assessed in terms of power tools' handle vibration transmission to the palm of the hand using the method described in ISO 10819 (2013), while the nature of vibration transmitted to the fingers is ignored. Moreover, the VR gloves with relatively low stiffness viscoelastic materials affect the grip strength in an adverse manner. This study is aimed at performance assessments of 12 different VR gloves on the basis of handle vibration transmission to the palm and the fingers of the gloved hand, together with reduction in the grip strength. The gloves included 3 different air bladder, 3 gel, 3 hybrid, and 2 gel-foam gloves in addition to a leather glove. Two Velcro finger adapters, each instrumented with a three-axis accelerometer, were used to measure vibration responses of the index and middle fingers near the mid-phalanges. Vibration transmitted to the palm was measured using the standardized palm adapter. The vibration transmissibility responses of the VR gloves were measured in the laboratory using the instrumented cylindrical handle, also described in the standard, mounted on a vibration exciter. A total of 12 healthy male subjects participated in the study. The instrumented handle was also used to measure grip strength of the subjects with and without the VR gloves. The results of the study showed that the VR gloves, with only a few exceptions, attenuate handle vibration transmitted to the fingers only in the 10–200 Hz and amplify middle finger vibration at frequencies exceeding 200 Hz. Many of the gloves, however, provided considerable reduction in vibration transmitted to the palm, especially at higher frequencies. These suggest that the characteristics of vibration transmitted to fingers differ considerably from those at the palm. Four of the test gloves satisfied the screening criteria of the ISO 10819 (2013) based on the palm vibration alone, even though these caused amplification of handle vibration at the fingers. The fingers' vibration transmission performance of gloves were further evaluated using a proposed finger frequency-weighting $W_f$ apart from the standardized $W_h$-weighting. It is shown that the $W_h$ weighting generally overestimates the VR glove effectiveness in limiting the fingers vibration in the high (H: 200–1250 Hz) frequency range. Both the weightings, however, revealed comparable performance of gloves in the mid (M: 25–200 Hz) frequency range. The VR gloves, with the exception of the leather glove, showed considerable reductions in the grip strength (27–41%), while the grip strength reduction was not correlated with the glove material thickness. It is suggested that effectiveness of VR gloves should be assessed considering the vibration transmission to both the palm and fingers of the hand together with the hand grip strength reduction.



## 1. Introduction

Workers operating hand-held power tools are occupationally exposed to comprehensive levels of hand transmitted-vibration (HTV), which has been associated with various disorders of hand and arm (Gemne and Taylor, 1983; Griffin, 1990; Pelmear and Wasserman, 1998). Anti-vibration (AV) gloves are commonly viewed as simple and convenient mean to limit the HTV levels (Griffin et al., 1982; Goel and Rim, 1987; Reynolds et al., 1996). International Organization for Standardization (ISO) has set forth a screening criterion for classifications of a glove as an AV glove on the basis of measurement of vibration transmitted to the palm of

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the gloved hand (ISO 10819, 2013), while the measurements of vibration transmitted to the fingers is not required. A glove is considered as an AV glove when the frequency-weighted palm acceleration transmissibility magnitudes in the medium (M: 25–200 Hz) and high (H: 200–1250 Hz) frequency ranges are ≤0.9 and ≤0.6, respectively. Moreover, the standard requires that fingers section of the glove should employ same vibration isolation material as the palm, while its thickness must be at least 55% of that in the palm region. This suggests that the standard likely assumes similar vibration transmission to both the palm and the fingers. A few recent studies have invariably shown that VR gloves yield widely different vibration responses at the palm and fingers (Welcome et al., 2014; Hamouda et al., 2015). This is likely due to widely different vibration characteristics of the fingers compared to those of the palm and the hand arm system (Dong et al., 2008b, 2009, 2013). Moreover, the effective mass of the fingers is substantially smaller than that of the palm-arm system, which may contribute to differences in the isolation effectiveness of VR gloves at the palm and the fingers.

A recent study has experimentally characterized the fingers' vibration responses of two types of VR gloves employing gel and air bladder vibration isolation material in the palm and finger sections (Welcome et al., 2014). Hewitt et al. (2015) used the data reported by Welcome et al. (2014) to estimate the finger vibration transmissibility of an air bladder glove under vibration of different tools using the frequency response function. Both the studies showed none or minimal attenuation of handle vibration transmitted to the fingers. Md Rezali and Griffin (2015) evaluated the effect of glove material (foam and gel) thickness by measuring the vibration transmitted to the palm and distal phalange of the index finger (tip). It was shown that the glove material reduced vibration at the palm in the 20–350 Hz frequency range but increased the vibration at the fingertip. Hamouda et al. (2015) measured the handle vibration transmitted to mid-phalanges of the index and middle fingers, which exhibit the highest vibration transmissibility compared to the proximal and distal phalanges of the fingers of the hand coupled with four different types of VR gloves (air, gel, hybrid, and leather). The hybrid glove was constructed with air pockets in the palm region and gel pad in the fingers region. The results showed that the VR gloves generally reduce fingers vibration in the 10–200 Hz frequency range and amplify vibration in the 200–600 Hz range, except for the air glove. Welcome et al. (2014) concluded that the gel glove was more effective in reducing fingers vibration at higher frequencies (>400 Hz) as compared with the air bladder glove, while Hamouda et al. (2015) concluded that air glove was more effective at higher frequencies (>200 Hz). Furthermore, Welcome et al. (2014) reported that the resonance frequencies of the fingers of the gloved hand were similar to those of the bare hand, although the gel glove resulted in relatively lower index finger resonant frequency. Hamouda et al. (2015), on the other hand, reported relatively higher resonant frequencies of the index and middle fingers when coupled with the gloves.

The spectra of vibration measured at the palm of the gloved hand, reported in different studies (e.g., Welcome et al., 2012; McDowell et al., 2013), generally show resonant peaks in the 20–30Hzrange suggesting amplification of handle vibration transmitted to the palm in this frequency range. The frequency weighting, $W_h$ (ISO 5349-1, 2001), used for evaluating vibration transmission performance of the gloves also emphasizes the palm vibration up to about 25 Hz. Different from the palm, the spectra of finger-transmitted vibration (Welcome et al., 2014; Hamouda et al., 2015) generally exhibit resonant peaks in the 80–200 Hz frequency range depending on the type of VR gloves or the vibration isolation material. Studies reporting biodynamic responses of the hand and arm system have also suggested substantially higher resonant frequencies of the fingers compared to the palm and the hand-arm structure (Dong et al., 2008a, 2009; 2013). Considering that the $W_h$ weighting substantially attenuates vibration in this frequency range, a number of studies have expressed concerns over adequacy of the standardized weighting for assessing fingers vibration exposure (Dong et al., 2005, 2008a; Bovenzi et al., 2000, 2011). Dong et al. (2008a) proposed an alternate finger weighting ($W_f$) on the basis of measured vibration biodynamic responses of the fingers in terms of vibration power absorption (VPA). The study showed that VPA distributed in the palm–wrist and arm correlates well with $W_h$-weighted vibration, while it can greatly underestimate high-frequency effects on the development of finger disorders. The proposed $W_f$–weighting provided greater emphasis on fingers vibration up to 500 Hz frequency range considering the fingers resonances at higher frequencies.

It has been suggested that reducing the glove material stiffness and optimizing its damping could help enhance isolation effectiveness of the VR gloves (Dong et al., 2009; Hewitt et al., 2015). The use of low stiffness materials such as air pockets, foam or gel-foam combinations, however, would yield greater thickness of the glove. Thick and bulky gloves are known to limit the manual hand dexterity, which may discourage the use of gloves by the operators (Dianat et al., 2012). It has been further shown that gloves in general require increased grip effort of the workers (Fleming et al., 1997; Cabeças and Milho, 2011), and thereby limit the effective hand grip strength (Wimer et al., 2010). Usually workers tackle the reduced hand grip strength by applying higher hand grip force and thus increase the effort. The increased grip effort may increase the risk of hand-arm disorders such as carpal tunnel syndrome (Silverstein et al., 1987; Bernard and Putz-Anderson, 1997). Many studies have investigated the grip strength reduction due to gloves (Muralidhar et al., 1999; Buhman et al., 2000; Jung and Hallbeck, 2004; Chang and Shih, 2007; Wimer et al., 2010; Welcome et al., 2012). The majority of these studies have employed Jamar dynamometer for measuring the grip strength reduction due to VR gloves, although the dynamometer handle is not representative of a tool handle, which is cylindrical in many vibrating tools (Dong et al., 2008c; Wimer et al., 2010). Instrumented cylindrical handles have been employed in a few studies for measurement of the grip strength in a power grip condition corresponding to maximum voluntary contraction effort (Wimer et al., 2010). The study employed six different gloves including two conventional gloves and four VR gloves with different isolation materials (air bladder, air pump bladder, leather, and gel) and concluded that all of the VR gloves reduced the grip strength by more than 29%, while one of the conventional gloves resulted in less than 10% deterioration in the grip strength. The study also showed greatest reduction in grip strength by the relatively thick air glove. Welcome et al. (2012) measured the grip strength due to 15 different VR gloves (air bladder, gel pad, and air bladder with pump), and showed comparable grip strength reduction of all the gloves (30–42%). Greatest reduction was obtained with the gel glove.

The current standard (ISO 10819, 2013) for screening of VR gloves is based solely on the magnitude of handle vibration transmitted to the palm of the gloved hand. The vibration transmitted to the fingers of the gloved hand, and reductions in grip strength and manual dexterity also constitute important factors in describing the performance of VR gloves. The preservations of the grip strength and hand dexterity are particularly vital for promoting the use of VR gloves among the vibrating hand tools operators. An integrated performance measure addressing the aforementioned factors thus needs to be defined so as to seek improved designs of VR gloves.

This study explores the performance of VR gloves on the basis of the handle vibration transmitted to the palm and fingers of the gloved hand, and the grip strength reduction. The validity of a