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A Method for Reducing Adaptor Misalignment when Testing Gloves Using ISO 10819

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Objectives: International standard ISO 10819 was established in order to quantify the vibration attenuation characteristics of anti-vibration gloves. One problem that exists with the standard is possible misalignment of the palm adaptor that is placed underneath the test glove. If the adaptor becomes misaligned, the measured glove transmissibility will be lower than the actual value. A tri-axial accelerometer was installed in the adaptor and was used as the basis for providing visual feedback of the adaptor alignment to the test subjects. The objective of this study was to test the hypothesis that adaptor misalignment could be reduced by providing feedback to the test subjects.

Methods: Eight male volunteers (mean age 24.8 yr) were used in the study. Each subject performed two sets of tests: the standard ISO 10819 glove test and the modified version. Three different anti-vibration gloves were tested. Glove transmissibility and adaptor misalignment were calculated for each glove. A three-way analysis of variance was used to analyze the results.

Results: A comparison of the two testing methods showed that the modified glove testing method did reduce misalignment significantly, which, in turn, resulted in an increase in the measured glove transmissibility.

Conclusions: The proposed method greatly improved the standard deviation of transmissibility and made the test results more consistent.

Keywords: vibration; glove testing; vibration exposure

INTRODUCTION

Power hand tools such as chainsaws, pneumatic hammers, drills and grinders are commonly used in many industrial settings. Prolonged use of these types of tools has been related to a series of disorders in the vascular, sensorineural and musculoskeletal systems of the hand and arm (Griffin, 1990; Pelmear and Wasserman, 1998). These disorders have been collectively defined as hand–arm vibration syndrome (HAVS) (Gemne and Taylor, 1983). It is estimated that between 30 and 90% of all workers exposed to chronic hand–arm vibration will eventually develop the disorder (Taylor, 1989). HAVS is a multi-factor disease, involving pathologies of the nervous, vascular and musculo-skeletal systems, with vascular disorders being the most common pathology (Griffin, 1990). Symptoms of HAVS include vasospasms in response to cold temperature, numbness and paresthesia in the hands and impaired grip strength.

Gloves have been viewed as one method to help protect workers from HAVS. In addition to helping keep the hands warm and dry, gloves can also reduce the amount of vibration transmitted from the tool to the hands and fingers. The vibration transmissibility characteristics of some gloves have been measured by several investigators (Griffin *et al.*, 1982; Goel and Rim, 1987; Rens *et al.*, 1987; Starck *et al.*, 1990; Gurram *et al.*, 1994). Overall, only a few of the gloves tested have shown good attenuation of vibration. It was found that most gloves provided some attenuation of vibration at frequencies >100 Hz, but that at frequencies <100 Hz, some gloves actually increased the amount of vibration transmitted to the hands (Gurram *et al.*, 1994).

In order to quantify the vibration attenuation characteristics of different gloves, international standard ISO 10819 (International Standards Organisation, 1996) was established. The test method described in

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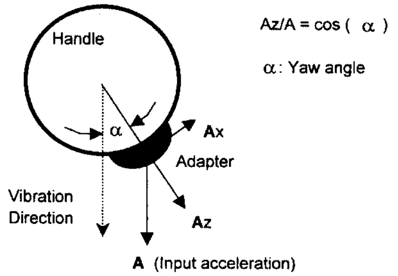
ISO 10819 employs human volunteers that grasp a handle attached to a horizontal shaker. The handle is instrumented to measure acceleration and grip force. A force plate is also used to measure how hard the volunteers push on the handle (feed force). A small, light-weight adaptor, which measures acceleration, is placed in the palm of the hand underneath the glove. The test subject then grips the shaker handle with a pre-determined force while the shaker vibrates. By measuring the amplitude of the vibration simultaneously at the surface of the handle and with the adaptor in the palm of the hand, the amount of vibration transmitted through the glove can be calculated. This quantity is referred to as the glove transmissibility. To calculate the transmissibility for a specific glove, three volunteers are used. Each volunteer uses the same glove, which is tested under two input vibration spectra (medium and high range) that have been defined by ISO 10819. The medium range spectrum (M spectrum) covers a frequency range from 16 to 400 Hz and the high range frequency (H spectrum) covers a range from 100 to 1600 Hz.

Unfortunately, some problems exist with the present ISO standard. One of these problems is misalignment of the adaptor that is held in the palm. The adaptor can easily become misaligned because it is inside the test glove and cannot be seen. If the adaptor becomes misaligned, the measured glove transmissibility will be lower than the actual value (Fig. 1). Hewitt reported that during testing the palm adaptor could be as much as 40° out of alignment, a condition that could result in a decrease in the transmissibility of up to 20% (Hewitt, 1998). Clearly, alignment of the adaptor is extremely important if accurate glove testing is to be performed.



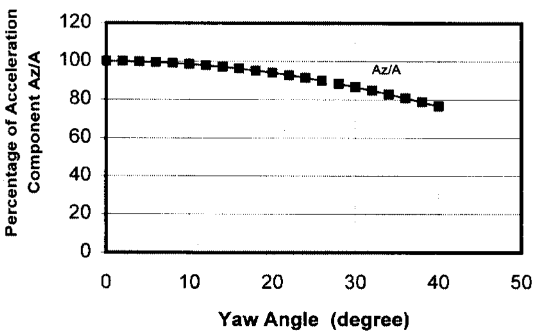


Fig. 1. Analysis of palm adaptor misalignment.

One method suggested to reduce misalignment of the adaptor is to open the glove along a seam between the thumb and the forefinger, so that the adaptor can be seen and thus aligned properly (Hewitt, 1998). However, there are cases where altering the glove is undesirable. An example would be gloves that are borrowed from workers, tested and then returned to the worker. In addition, cutting a hole in the glove may alter the glove transmissibility (Hewitt, 1998).

A different solution to reducing adaptor misalignment is proposed by the authors of this paper. If the single-axis accelerometer in the palm adaptor were replaced with a three-axis accelerometer, then the acceleration data from the additional two axes could be utilized to determine the extent of adaptor misalignment. If this information were to be provided in real time to the test subjects, they could adjust the adaptor to minimize any misalignment. Testing of this concept was the focus of this research.

MATERIALS AND METHODS

Apparatus

The test apparatus and palm adaptor were built in accordance with ISO 10819. The only exception was that a three-axis accelerometer (ENDEVCO 35A-Z) instead of the recommended single-axis accelerometer was installed in the palm adaptor. The adaptor was made of titanium and weighed 15.7 g, which is slightly higher than the maximum weight of 15.0 g recommended by ISO 10189. The test apparatus consisted of an electro-mechanical shaker (Unholtz Dickie S032) that was mounted horizontally on a platform, a power amplifier (Unholtz Dickie TA250), a closed loop controller (Unholtz Dickie UD-VWIN), an instrumented handle, a force plate (Kistler 9286AA), the palm adaptor and a data acquisition and analysis system (Bruel and Kjaer 2816). A schematic of the test apparatus is shown in Fig. 2.

Three different anti-vibration gloves were tested; two that used air bladders (gloves 1 and 2) to dampen the vibration and one that used foam padding in the palm (glove 3).

Subjects

Eight male volunteers (mean age 24.8 yr) were used in the study. The volunteers were in good health and did not have a history of HAVS. The study participants were recruited from the local university and from other branches within NIOSH. The protocol was reviewed and approved by the NIOSH Human Subjects Review Board.

All of the volunteers were informed about the general objectives of the research, the test protocol and the confidentiality of the results. It was empha-

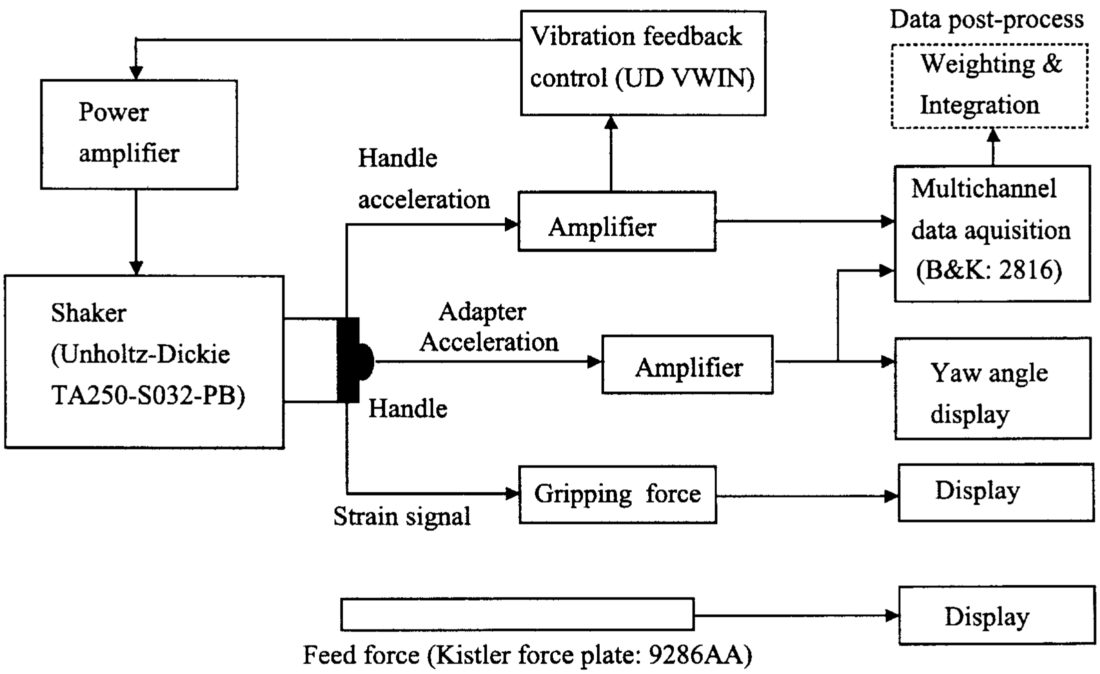


Fig. 2. Schematic of the test set-up for ISO 10819 testing.

Table 1. Subject demographics

Subject	Age	Height (cm)	Weight (kg)	Hand length (cm)	Hand width (cm)	Hand thickness (cm)
M84	21	191	89	21.0	9.0	3.3
E26	22	178	95	18.2	9.0	3.0
K42	25	180	73	18.0	9.1	2.5
X30	20	185	80	19.5	8.6	3.1
G50	20	170	97	19.0	9.0	4.4
N97	31	183	82	19.0	8.5	2.5
P71	29	178	68	19.7	8.5	2.7
Y10	30	193	93	19.5	9.3	3.5

sized that their participation was strictly voluntary and that they were free to withdraw from the study at any time. After reading and signing a consent form, the weight, height, age and length, width and thickness of the right hand were recorded for each test subject (Table 1). The test subjects were then shown how the tests were to be conducted and were allowed to practice until they became comfortable with the test protocol.

Method

Each test subject performed two sets of tests; the standard ISO 10819 glove test (both the M and H vibration spectra) and the modified version which provided the test subjects with feedback of the misalignment of the palm adaptor. Each set of tests was performed on a different day and took ~2.5 h to complete. The standard ISO 10819 glove test was always performed before the modified version. This was to ensure that information concerning positioning of the adaptor learned during the modified version of the glove test did not bias adaptor placement during the standard ISO 10819 glove test. However, the order in which the gloves were tested and the order in which the vibration spectra were presented were randomized.

The standard glove test was done in accordance with the method described in ISO 10819. Briefly, the test protocol was as follows. The test subjects stood upright on the force plate, facing the shaker (Fig. 3). After placing the adaptor in the palm of their right hand underneath the glove, they were asked to grasp the handle of the shaker (forearm horizontal to the floor, elbow angle 90 ± 10° and wrist angle between 0° and 40° extension). The test subjects were asked to maintain a grip force of 30 ± 5 N on the handle and a feed force of 50 ± 8 N. Real time display of the grip force and feed force was provided via a computer to the test subjects. The shaker was then turned on and one of the vibration spectra (M or H) was input to the shaker. Output from the two accelerometers, the force plate and the instrumented handle were recorded for a period of 30 s and stored on a computer. The test was then stopped and the tests subjects were given a 3 min rest period. The three gloves were each tested three times. The order of the nine glove tests was randomized for each test subject. In addition, one test was performed where the test subject held the adaptor in his bare hand. This test was always performed

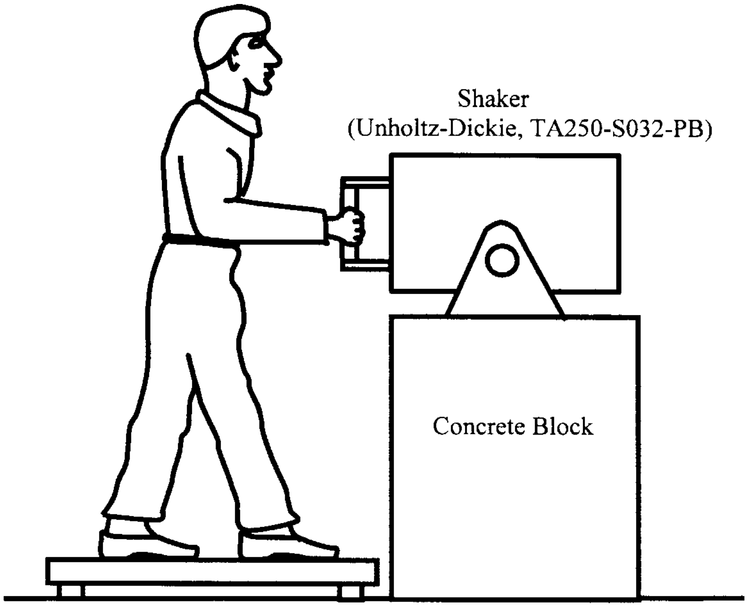


Fig. 3. Position of the human volunteer during glove testing.

before the nine glove tests. The process was then repeated for the other vibration spectrum (either M or H).

The modified glove test followed the same protocol as the standard test except that the subject was asked to adjust the position of the palm adaptor to minimize the yaw misalignment before the test data were collected. Theoretically, the ratio of the acceleration in the *x*-direction (A_x) to that in the *z*-direction (A_z) is a tangent function of the yaw angle (Fig. 1). However, the instantaneous ratio was not used for the display because the value of A_z can become null in real time. In addition, the instant value may not be stable, which would make it difficult for the subject to adjust the adaptor position effectively. For these reasons, the ratio of the average absolute accelerations for a short period was used to represent the yaw angle. It is written as:

$$\tan(\alpha)_{t+\Delta t} = \frac{\int_{t}^{t+\Delta t} |A_x| \mathrm{d}t}{\int_{t}^{t+\Delta t} |A_z| \mathrm{d}t}$$

where *t* is the time and Δt is the time interval taken to refresh the display. In this study Δt was taken as 1 s, which gave a very stable display. The ratio was manually recorded during the test at a time when the display was stable. The yaw angle was eventually calculated using the recorded ratio.

Data reduction

Glove transmissibility data were assessed in accordance with ISO 10819. Briefly, the procedure was as follows. First, a spectral analysis was performed on the raw acceleration data from each test to determine the magnitude of acceleration across the entire frequency range (M or H spectra). Next, the data were multiplied by a frequency-weighting factor and then integrated over the frequency range (M or H spectra) to obtain the root mean square (r.m.s.) value of acceleration. A transmissibility value for each glove was calculated by dividing the weighted r.m.s. acceleration of the adaptor by the weighted r.m.s. acceleration of the handle.

Statistical analysis

The data were analyzed using SAS System v. 8.0 (SAS Institute, Cary, NC). Calculated transmissibility measures were incorporated into a three-way analysis of variance (glove × method × frequency) using PROC MIXED. 'Subject' was utilized as a random component and incorporated into the model for correct calculation of the error terms in the *F*-tests. In a separate analysis, the yaw angle was incorporated as a covariate associated with each measure of transmissibility. *Post-hoc* analyses were performed where appropriate using Fisher's LSD. All differences were considered significant at $P < 0.05$.

Table 2. Adaptor misalignment angle

Glove	Frequency	Standard method mean (SD)	Feedback method mean (SD)
1	M	24.9 (15.0)	10.6 (4.0)
2	M	27.1 (16.0)	11.2 (5.3)
3	M	15.8 (13.9)	10.7 (3.2)
1	H	30.8 (16.8)	13.6 (5.4)
2	H	33.6 (19.6)	12.7 (8.2)
3	H	15.2 (17.6)	4.2 (3.3)

Table 3. Glove transmissibility

Glove	Frequency	Standard method mean (SD)	Feedback method mean (SD)
1	M	0.802 (0.075)	0.876 (0.057)
2	M	0.813 (0.087)	0.885 (0.046)
3	M	0.912 (0.064)	0.950 (0.032)
1	H	0.486 (0.081)	0.579 (0.068)
2	H	0.552 (0.117)	0.625 (0.063)
3	H	0.797 (0.130)	0.882 (0.045)

RESULTS

A comparison of the two test methods shows that the modified test method did reduce the misalignment angle (Table 2), which, in turn, resulted in an increase in glove transmissibility (Table 3).

Yaw angle

Analysis of the yaw angle indicated significant main effects of glove [$F(2,14) = 24.46$, $P < 0.0001$] and method [$F(1,7) = 7.61$, $P = 0.0281$]. However, there was a significant interaction between these two variables [$F(2,14) = 16.9$, $P = 0.0002$] and a significant interaction between glove and frequency [$F(2,14) = 10.24$, $P = 0.0018$]. The interaction between method and glove indicates that the improvement in yaw angle maintenance under the new method is dependent upon the glove used. Specifically, the new method improves angle maintenance with gloves 1 and 2, however, there is only slight, non-significant improvement when glove 3 is used. This is a result of the subject's ability to better maintain the angle under both methods when glove 3 is used and does not seem to be due to any lack of effectiveness of the feedback procedure. It seems that glove 3 might be more flexible or sensitive, since with both the conventional method and the new method glove 3 showed significantly lower values on the angle measure than glove 1 or 2, while gloves 1 and 2 do not differ from one another within either test condition.

This characteristic of glove 3 is further evident in the glove × frequency interaction. With gloves 1 and 2 angle maintenance is better under medium frequency than under high frequency stimulation, while there is no difference between the two frequencies when glove 3 is used. Further, within a testing frequency and irrespective of method used, subjects are better able to maintain the yaw angle when using glove 3 than when using glove 1 or 2, while gloves 1 and 2 do not differ from one another when tested using either frequency.

Transmissibility

The model fitting transmissibility as a function of glove, method and frequency indicated that there were significant main effects of glove [$F(2,14) = 309.7$, $P < 0.0001$], method [$F(1,7) = 13.82$, $P = 0.0075$] and frequency [$F(1,7) = 205.3$, $P < 0.0001$]. However, there was a two-way interaction between glove and frequency [$F(2,14) = 103.73$, $P < 0.0001$], indicating that the main effects of these variables are not sufficient to explain all of the data. There were no significant interactions between glove and method [$F(2,14) = 0.80$, $P = 0.4670$] and method and frequency [$F(1,7) = 0.98$, $P = 0.3553$], and no three-way interaction between glove, method and frequency [$F(2,14) = 1.15$, $P = 0.3447$].

Analysis of the main effect of method indicated that transmissibility was greater using the new method relative to the old method (0.7272 versus 0.7995). Analysis of the simple main effects of frequency for each glove indicated that in all cases (Table 3) the transmissibility was greater under conditions of medium frequency stimulation relative to high frequency stimulation. The source of the interaction is due to the fact that the magnitude of this difference between the two frequencies is much less for glove 3 than for glove 1 or 2. However, with one exception, within each frequency tested each glove is significantly different from the other gloves tested at that same frequency. The exception is that glove 1 is not significantly different from glove 2 at the medium frequency.

Analysis of variance using angle as a covariate indicated that angle is a significant covariate [$F(1,191) = 88.96$, $P < 0.0001$]. Further, when angle is accounted for in the model, there is no longer a significant difference between the two methods of testing [$F(1,7) = 3.83$, $P = 0.0911$]. The adjusted least squares means when angle is accounted for are 0.7505 for the conventional method and 0.7752 for the new method. All other results in this analysis are similar to those reported above.

DISCUSSION AND CONCLUSION

This study has shown that the modified test method using feedback proposed by the authors resulted in better alignment of the palm adaptor during testing. This better alignment in turn resulted in increased glove transmissibility. According to ISO 10819 gloves are only classified as anti-vibration gloves if the transmissibility is <1.0 for the M spectrum and <0.6

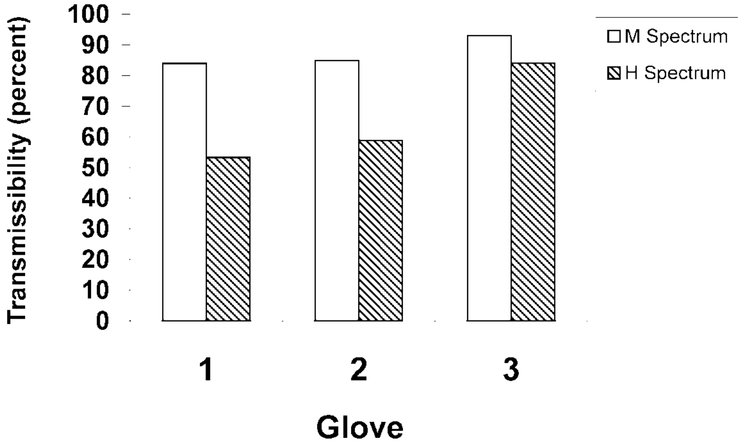


Fig. 4. Comparison of transmissibility for the three gloves for both vibration spectra.

for the H spectrum. Using the standard test method, glove 2 would have been classified as an anti-vibration glove for the H spectrum. However, using the modified method, glove 2 would not have been classified as an anti-vibration glove because the transmissibility exceeded 60%. Obviously, alignment of the palm adaptor is critical if accurate transmissibility values are to be obtained for anti-vibration gloves using ISO 10819.

As shown in Table 3, the standard deviations from the modified test method were all less than those from the standard test method, many reduced by 50% or more. This suggests that the proposed method is more robust and reliable than the standard method. The covariate-related finding that statistically removing the effects of the variation in yaw angle effectively eliminates the differences in the two methods further reinforces the importance of the need to carefully align the adaptor.

Of the gloves tested, glove 1 yielded the best vibration attenuation and glove 3 yielded the poorest (Fig. 4). As expected, all three gloves did a better job of attenuating vibration at higher frequencies that they did at lower frequencies.

Adaptor misalignment using the standard method was less for glove 3 than for the other two gloves. This was felt to be caused by the design of the glove. The design of glove 3 provided more space around the thumb, which allowed the test subjects to position the adaptor more in the web of the hand (between the thumb and index finger), which resulted in a better alignment.

One potential criticism of this study is that the standard ISO 10819 glove test was always performed before the modified version. As mentioned earlier, this was done to ensure that information gained concerning adaptor positioning using feedback did not bias adaptor placement during the standard glove test. This approach allowed for the possibility of a learning effect between the two sessions that was not controlled for. However, the authors feel that if this learning effect does exist, it is relatively small and did not effect the results significantly.

The method proposed by the authors is not without its practical concerns. The first is the increased cost of the three-axis accelerometer as compared to a single-axis accelerometer. Second, there is the added cost of two more signal conditioners and the other hardware needed to collect three, instead of one, channels of data. Third, is the added time required to align the adaptor before data collection can begin. Fourth, it was found that some subjects attempted to align the adaptor by increasing wrist flexion rather than moving the adaptor inside the glove. A few subjects came very close to exceeding 40° wrist extension (the maximum allowed by ISO 10819) while trying to align the adaptor. The experience of this study also suggests that during the test subjects should wear a slightly larger glove than they would normally wear for actual work, so that they can more easily adjust the position of the adaptor inside the glove to obtain the desired alignment.

In conclusion, the authors found that providing feedback to the test subject resulted in better adaptor alignment and thus more accurate glove transmissibility values. They believe that this increased accuracy outweighs the added cost of the tri-axial accelerometer and recommend that this new method be considered by other groups when doing glove testing in accordance with ISO 10819.

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