# Evaluation of Anti-Vibration Gloves in a Manufacturing Setting

Andrew Forbes

A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Science Environmental and Occupational Exposure Science

University of Washington

2013

Committee:

Peter W. Johnson

Randal P. Ching

Stephen S. Bao

Program Authorized to Offer Degree:

School of Public Health

University of Washington

**Abstract**

Evaluation of Anti-Vibration Gloves in a Manufacturing Setting

Andrew Forbes

Chair of the Supervisory Committee:
Associate Professor Peter W. Johnson
Department of Environmental & Occupational Health Sciences

While anti-vibration gloves are widespread as a form of reducing employee exposure to hand-arm vibration (HAV) there is concern about how effective they actually are in a real manufacturing environment with specific tools. Currently ISO 10819 is used to certify gloves as “anti-vibration”; however, the standard only tests a static position and force which may not accurately represent a gloves ability to reduce vibration exposure during specific tasks.

The aims of this study are to examine 4 different types of gloves and see how effective they are at reducing vibration exposure in employees performing a specific workplace task. The first hypothesis tested is whether or not the gloves are different from the bare hand measurements. The null hypothesis is that there is no difference in vibration exposure when a glove is used. The second hypothesis evaluated is whether a difference can be observed between the gloves themselves. The null hypothesis is that there is no difference between the gloves. To determine the validity these two hypotheses, vibration exposure during a sanding task will be examined. The third hypothesis tested is whether the subjects’ perception of vibration reduction with the gloves matches the actual measured results. The null hypothesis is that there is no difference between subject perception and the measured results. This was done with a

questionnaire given to the subjects asking them to rate the perceived vibration and rank the gloves in order of most effective to least.

A jitterbug-style orbital sander was mounted with a tri-axial accelerometer while the subject had another tri-axial accelerometer attached to the back of their hand and both were connected to the same data logger so that simultaneous measurements of both accelerometers could be taken. In a randomly assigned order the subject used each of the four gloves to take one minute samples from sanding both a vertical and a horizontal surface. The same was done for a barehanded measurement where the subject used no glove, also randomly assigned in the order. A ratio from the tool and hand samples was found for each glove to find the transmissibility factor. The gloved transmissibility factors were then compared to that subject's bare hand sample to find the corrected transmissibility of the glove.

The results differed depending on which surface was used. On the horizontal surface there was not a significant difference between the gloves and the bare hand, but if the sample size would have been larger then there likely would have been. There was a significant difference between gloves; one of the gloves was found to amplify vibration exposure. On the vertical surface there was no difference between the gloves and the bare hand or between the gloves themselves. The subject rankings of the gloves did not closely resemble the actual results.

According to this study, ISO 10819 may not accurately depict a glove's ability to mitigate vibration for specific tasks. The use of anti-vibration gloves may also be an ineffective way to try to reduce employee exposure to high levels of vibration.

# List of Figures

Figure 1: UK HAV “Ready Reckoner” Exposure System........................................4
Figure 2: Glove Types.............................................................................11
Figure 3: Placement of Accelerometer ......................................................13
Figure 4: LM Spar....................................................................................14
Figure 5: Hand Pressure on Accelerometer Plot ...........................................18
Figure 6: Surface Vector Sum Comparison Plot...........................................19
Figure 7: Hand Vector Sum Surface Comparison Plot ...................................20
Figure 8: Tool Vector Sum Surface Comparison Plot.....................................20
Figure 9: Horizontal Surface-Dependent Sampling Order ..............................21
Figure 10: Vertical Surface-Dependent Sampling Order ................................22
Figure 11: Hand Surface-Independent Sampling Order ..................................22
Figure 12: Tool Surface-Independent Sampling Order....................................23
Figure 13: Glove CT Horizontal Surface Plot ................................................24
Figure 14: Glove CT Vertical Surface Plot.....................................................25
Figure 15: Horizontal Glove by Subject Interaction ........................................25
Figure 16: Vertical Glove by Subject Interaction.............................................26

# List of Tables

Table 1: TLVs® for Exposure of the Hand to Vibration ........................................3
Table 2: Latin Square Model Used in Testing ....................................................14
Table 3: Dunnett's Test of the CT's from the Horizontal Surface ........................24
Table 4: Dunnett's Test of the CT's from the Vertical Surface.............................25
Table 5: Subject Glove Ranking..........................................................................26
Table 6: Borg Scale Responses...........................................................................27

# Introduction

## Hand-Arm Vibration

### *Prevalence of Hand-Arm Vibration*

There are millions of workers in many different industries who are exposed every week to hand arm vibrations (Palme, Griffin, Syddal, Pannett, & Coggon, 2000). While the exposure is widespread, there is a lack of understanding among many employers and employees about how damaging the effects of hand arm vibrations can be. With varying times to symptoms onset ranging from weeks to several years, many workers don't understand that there symptoms may be associated with vibrating hand tool use. Further work is needed to investigate what tool vibration frequencies are the most damaging in order to more fully elucidate the dose-response relationship between vibrating hand tool use and various vibration-related upper extremity musculoskeletal disorders.

In order to examine the scope of exposure, a study in Great Britain was undertaken to try to establish how many workers were exposed to occupational HAV. The study concluded that at least "4.2 million men and 667,000 women in Great Britain are exposed to HAV at work in a 1 week period" (Palme, Griffin, Syddal, Pannett, & Coggon, 2000). The study also noted that, of those 4.2 million men and 667,000 women, there were 1.2 million men and 44,000 women who were exposed to vibrations exceeding the suggested hand-arm vibration action limits. The picture is most likely very similar in the United States, but there is even less data about how many American workers are exposed to HAV and to what magnitudes.

The large number of people exposed to HAV is reflective of the myriad of occupations that involve work with vibrating hand tools. Carpenters, construction workers, motor mechanics, are but a few of the many types of laborers exposed to vibrating hand tool use on a daily basis. In fact, carpenters and construction workers are some of the most at-risk jobs for developing serious disability due to HAV (Palmer, et al., 2001). Common tools that may cause HAV are impact wrenches, orbital sanders, jack hammers, drills, grinders, chain saws, and many other types of vibrating tools are sources as well. An employee does not have to be operating a tool or piece of machinery to be at risk for HAV. A worker could be using a hand-guided tool or be holding onto an object that is itself being vibrated, such as a pedestal grinder or bucking bar during a riveting process (Worried about your hands?, 2011).

*Regulation and Assessment*

The best way to assess HAV is currently a topic of debate among occupational health professionals. At the moment, the current assessment method in the United States, referenced by both The Occupational Safety and Health Administration (OSHA) and The American Conference of Governmental Industrial Hygiene (ACGIH) is ISO 5349 which consists of a tri-axial accelerometer mounted onto the tool being assessed (ACGIH, 2012) (OSHA, 2008). The vibrations are recorded by a vibration dosimeter and the vibration signal is weighted for those frequencies that the upper extremities appear to be most sensitive to. According to the OSHA Technical Manuel Section II Chapter 3, the frequencies the hand is most sensitive to “appears to be around 8-16 Hz” (OSHA, 2008). The vibration magnitude recorded by the accelerometer is usually given in $m/s^2$ and can then be compared to the vibration threshold limit values (TLV) recommended by ACGIH. The TLV gives suggestions on how long a worker can be safely exposed to vibration based on the magnitude.

OSHA does not have any regulations that directly regulate employee exposure to HAV, nor does it have a classification for recording vibration induced injuries or disorders. However, while there are no laws governing HAV in the United States, ACGIH has set up guidelines to prevent chronic symptom progression "beyond Stage 1 of the Stockholm Workshop Classification System for Vibration-induced White Finger (VWF), which is also known as Raynaud's Phenomenon of Occupational Origin" (ACGIH, 2012). Stage 1 of VWF is when the tips of the fingers have occasional attacks where there is a loss of blood flow and the tips blanch white. There may also be intermittent numbness possibly accompanied by a tingling sensation. The levels listed in table 1 show the maximum recommended exposure based on the magnitude of vibration. The European Union (EU) has also developed standards for worker protection to HAV displayed in Figure 1. EU values tend to be a similar to the ACGIH values given in the TLV. For example, the action limit for 8 hour HAV exposure in the United Kingdom is only 5 $m/s^2$, while the ACGIH limit is 4 $m/s^2$. However, these limits are only guidelines in the United States while in the EU standards are legally enforceable in the applicable nations.

**Table 1: TLVs® for Exposure of the Hand to Vibration**

| | Values of the Dominant, Frequency-Weighted, rms, Component Acceleration Which Shall not be Exceeded | |
|---|---|---|
| Total Daily Exposure Duration | $m/s^2$ | gΔ |
| 4 hours and less than 8 | 4 | 0.40 |
| 2 hours and less than 4 | 6 | 0.61 |
| 1 hour and less than 2 | 8 | 0.81 |
| Less than 1 hour | 12 | 1.22 |

**Figure 1: UK HAV “Ready Reckoner” Exposure System. The numbers in the cells can be used to determine exposure when an employee is exposed to multiple sources of vibration.**

| Vibration magnitude m/s² | 15 m | 30 m | 1 h | 2 h | 3 h | 4 h | 5 h | 6 h | 8 h | 10 h |
|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 800 | | | | | | | | | |
| 30 | 450 | 900 | | | | | | | | |
| 25 | 315 | 625 | 1250 | | | | | | | |
| 20 | 200 | 400 | 800 | | | | | | | |
| 19 | 180 | 360 | 720 | 1450 | | | | | | |
| 18 | 160 | 325 | 650 | 1300 | | | | | | |
| 17 | 145 | 290 | 580 | 1150 | | | | | | |
| 16 | 130 | 255 | 510 | 1000 | | | | | | |
| 15 | 115 | 225 | 450 | 900 | 1350 | | | | | |
| 14 | 98 | 195 | 390 | 785 | 1200 | | | | | |
| 13 | 85 | 170 | 340 | 675 | 1000 | 1350 | | | | |
| 12 | 72 | 145 | 290 | 575 | 865 | 1150 | 1450 | | | |
| 11 | 61 | 120 | 240 | 485 | 725 | 970 | 1200 | 1450 | | |
| 10 | 50 | 100 | 200 | 400 | 600 | 800 | 1000 | 1200 | | |
| 9 | 41 | 81 | 160 | 325 | 485 | 650 | 810 | 970 | 1300 | |
| 8 | 32 | 64 | 130 | 255 | 385 | 510 | 640 | 770 | 1000 | 1200 |
| 7 | 25 | 49 | 98 | 195 | 295 | 390 | 490 | 590 | 785 | 865 |
| 6 | 18 | 36 | 72 | 145 | 215 | 290 | 360 | 430 | 575 | 720 |
| 5.5 | 15 | 30 | 61 | 120 | 180 | 240 | 305 | 365 | 485 | 605 |
| 5 | 13 | 25 | 50 | 100 | 150 | 200 | 250 | 300 | 400 | 500 |
| 4.5 | 10 | 20 | 41 | 81 | 120 | 160 | 205 | 245 | 325 | 405 |
| 4 | 8 | 16 | 32 | 64 | 96 | 130 | 160 | 190 | 255 | 320 |
| 3.5 | 6 | 12 | 25 | 49 | 74 | 98 | 125 | 145 | 195 | 245 |
| 3 | 5 | 9 | 18 | 36 | 54 | 72 | 90 | 110 | 145 | 180 |
| 2.5 | 3 | 6 | 13 | 25 | 38 | 50 | 63 | 75 | 100 | 125 |
| 2 | 2 | 4 | 8 | 16 | 24 | 32 | 40 | 48 | 64 | 80 |
| 1.5 | 1 | 2 | 5 | 9 | 14 | 18 | 23 | 27 | 36 | 45 |
| 1 | 1 | 1 | 2 | 4 | 6 | 8 | 10 | 12 | 16 | 20 |

Daily exposure time

- Above limit value
- Likely to be above limit value
- Above action value
- Likely to be above action value
- Below action value

Recently there have been some questions and criticisms regarding the validity of ISO 5349 in general and the weighting of frequencies in particular. The hand-transmitted vibration working group (WG 3) of ISO technical committee ISO/TC 108/SC 4 Human Exposure to Mechanical Vibration and Shock decided that there was cause for concern with the way the current standard is written. They believe that there may be alternative weightings that could be used either in tandem with the current weighting or in place of it altogether (Pitts, Mason, Poole, & Young, 2011). This is not surprising since the current weightings, which are close to being 40 years old, were based on subjective perceptions to vibration rather than some of the more recently developed objective physiological methods. Many researchers have noted that current ISO 5349 standard weights lower frequencies too high and the higher frequencies too low (Brammer & Taylor, 1982) (Bovenzi, 1998). One set of researchers has introduced the idea of using vibration power absorption (VPA) methods to provide a better predictor for HAVS (Dong, Welcome, McDowell, Wu, & Schopper, 2005). This method is examining the use a different measurement type to establish a new frequency weighting that would allow for a much stronger prediction of how much damage is being done to the upper extremities.

**Prevention**

Because the effects of HAV can be so long lasting and damaging, there have been a number of methods implemented to try to reduce employee exposure to hand-arm vibration. Some of these methods include engineering controls such as anti-vibration tools, administrative controls like work rotations or scheduled breaks, and the use of personal protective equipment (PPE) like anti-vibration gloves. Regular tool maintenance is one way to greatly reduce vibration exposure that is sometimes ignored (Taylor, 1988). In fact, with the sanders that were used in this particular study it was found that proper maintenance could reduce vibration exposure. This fact was known to employees, but maintenance was not always done because if done improperly by an inexperienced maintenance employee the resulting problems with the sander could ruin the parts that were being worked on.

Other activities are used to prevent HAVS from developing. Cold hands can lead to an increased incidence of HAVS so keeping the hands warm helps to prevent white-finger syndrome from developing. Employees are often instructed to hold the tool as lightly as possible to reduce vibration transmission, and the tool should be operated at the lowest possible speed (Alaska Department of Labor and Workforce Development, 2013). While anti-vibration gloves are used in many work places, their effectiveness in reducing vibration exposure seems limited.

*Current Anti-Vibration Glove Evaluation (ISO 10819)*

With respect to anti-vibration gloves, international standard (ISO) 10819 (International Organization for the Standardization, 1996) specifies methods and procedures to determine whether a glove can be classified as an anti-vibration glove. Under fairly controlled laboratory conditions, the glove has to reduce vibration transmission by a certain percentage to be marketed as an anti-vibration glove. The glove is tested by having an individual, who does not necessarily have to have experience using vibrating hand tools, hold a vibrating vertical cylinder with a grip force of 30.0 N ± 5.0 and a push force of 50.0 N ± 8.0. The subject has a tri-axial accelerometer on the palm of the hand under the glove and a second tri-axial accelerometer is mounted on the vibrating cylinder. It is important to note that only vibration on the orthogonal axis is used to determine glove effectiveness; none of the shear vibration is taken into account. The cylinder is designed to vibrate at specific frequencies. The glove is tested in the medium frequency range from (31.5-200 Hz) and the high frequency range (200-1000 Hz). Three subjects are needed to fulfill testing requirements and then the gloves are evaluated using the following measurements and measurement outcomes:

$$Transmissibility(T) = \frac{Frequency\ weighted\ acceleration\ at\ the\ hand}{Frequency\ weighted\ acceleration\ at\ the\ tool}$$

and then,

$$Corrected\ Transmissibility\ (CT) = \frac{Gloved\ hand\ T}{Bare\ hand\ T}$$

Each of the subjects is tested twice, for a total of 6 measurements. The average of these six measurements is then used to determine the effectiveness. In order for the glove to be certified as an anti-vibration glove, it has to have a corrected transmissibility for the medium frequency range (31.5-200 Hz) of no more than 1. This means that there is no amplification of vibration in the medium range. The corrected transmissibility for the high frequencies also needs to be no more than 0.6, or a 40% reduction in vibration transmission, in order for the glove to be approved. If these requirements are not met then it is not considered an anti-vibration glove by ISO 10819. It should be noted that the American National Standards Institute (ANSI) has adopted ISO 10819 under the ANSI S2.73-2002 (2007) standard. Gloves that are labeled as ANSI certified are required to have passed this test.

*Concerns with ISO 10819*

There are a number of instances that may allow gloves to pass the ISO 10819 standard even though they don't actually reduce an employee's vibration exposure and, in some cases, may even increase the vibration exposure. For example, the fact that a constant pressure is required during the test is not very representative of what happens during vibrating hand tool use in the workplace. For many tasks, the worker is not simply holding a static object that is vibrating, but the tool (such as a sander or grinder) is constantly being moved and/or shifted while applying different amounts of grip force and/or pressure throughout the work process. Because the amount force used to grip a tool affects the transmission of vibration exposure to the hand and arm, this means that the ISO standard may not accurately reflect the actual protection (or lack thereof) of a glove (Farkkila, Pyykko, Korhonen, & Starck, 1979). And not only does the hand force change during most tasks using vibrating hand tools, but it is common for the worker to change the orientation of the tool and/or the way they are gripping the tool. All of the factors will affect the amount of vibration transmitted to the hand and arm of the tool operator.

Another potential problem with the ISO 10819 standard is the required placement of the accelerometer in the palm of the hand. While in an ideal setting the best place to measure the vibration would be in the glove-hand interaction point of the palm, there are a few problems associated with this accelerometer location. As described in (Dong, et al., 2003) the main problems with the palm accelerometer is that it can alter the way a subject grips the tool as well as change the contact conditions and amount of interfacing area. Placing the accelerometer on the back of the hand would eliminate these particular problems, but it would also introduce other sources of variability. For example, depending on the frequency of the vibrations passing through the hand, it is possible that the tissues of the hand may attenuate or amplify the signal. In order to overcome this, the samples taken from each subject should be compared to that subject's own bare hand transmissibility (T) as a reference, giving a corrected transmissibility (CT). This means that the non-corrected vector sum and transmissibility information will only be of limited use in analyzing the hand transmitted vibration data.

### Study Aims

It is not surprising that the current ISO 10819 standard may not be able to determine whether or not gloves reduce vibration in real workplace situations. Along with the problems with the grip force, tool orientation in the hand and accelerometer positioning, vibrating hand tools are often quite different in the frequency and magnitude of vibration (Rakheja, Dong, Welcome, & Schopper, 2002). The rotations per minute, size, weight, and engineering controls can all affect the frequency and magnitude. This means that while gloves may perform well in the laboratory tests, the laboratory tests may not be representative of how the gloves will perform in actual workplace settings. Basically, there are several key variables that do influence the amount of vibration a worker receives that are not accounted for in ISO 10819.

Therefore, given the prior work the aims hypotheses of this study are:

1. Evaluate the effectiveness of four gloves in reducing vibration from an orbital sander in an actual workplace setting.
2. Determine if there is a difference between the gloves in reducing vibration.
3. Determine if subject's perception of vibration reduction matches the actual objective measurement of the vibration reductions.

## Methods

### Study Design

The tool being examined was a jitterbug-style orbital sander (Mighty Midget; National Detroit; Love Park, IL) and the experimental task was the simulation of a process to remove resin from a long metal spar used as part of a process for manufacturing carbon fiber plane parts. The simulated task and tool were familiar to all of the recruited subjects.

*Subjects*

The study was conducted at an aircraft manufacturing plant using 10 subjects (4 men and 6 women) over two different shifts. Each of the subjects had the study explained to them and a filled out a consent form. The subjects had a mean age of 49.2 (Std Dev = 10.1) years with a minimum age of 29 and a maximum of 61. With respect to the tool that was used, the average years of experience subjects had using the tool was 7.3 (Std Dev 9.4) years, ranging from 0.1 years of a recent hire to 30 years, with an average self-reported weekly tool use of 14.7 hours (Std Dev 9.4), ranging from 0.1 to 33 hours. The subjects selected were representative of the subject population at the manufacturing facility. There was only one subject under the age of 40 in this test group. As the ISO 10819 standard currently is written, only three subjects are required to test anti-vibration gloves, so it was hoped using 10 subjects would compensate for the increased variability that may be associated with performing a standardized task in and actual workplace setting rather than in a lab.

*Gloves*

Four different gloves were selected to be tested. Two of the gloves were marketed specifically as anti-vibration gloves, although only one of them was actually ANSI certified as anti-vibration. The other two gloves were commonly available at the worksite and provided by the company. In both groups of gloves, the marketed anti-vibration marketed ones and the standard issue gloves, there was one pair of fingered gloves and one pair of fingerless gloves. It should be noted that a fingerless glove cannot be ANSI certified as anti-vibration but that does not mean it cannot be marketed by the company as anti-vibration. The actual design of the gloves differed greatly. As shown in Figure 2, Glove A (Proflex 9015; Ergodyne; St. Paul, MN), is an ANSI certified full-fingered glove that has a 5 mm thick Nu2O2® polymer layer on the palm and fingers of the hand. Glove B (BG401; Impacto; Belleville, Canada) is a fingerless glove that has a 3.2 mm thick honeycomb like padding of medium thickness on the palm and lower finger of the hand. Glove C (Proflex 910; Ergodyne; St. Paul, MN) was a fingerless glove with just 1.5 mm of padding but extra wrist support. Glove D was a (M-Pact Covert; Mechanix; Valencia, CA) was a full-fingered glove with thin padding (2.2 mm) on the palm but no extra padding anywhere else.

**Figure 2: The Glove Types**


*Experimental Protocol*

In order to test whether the gloves were effective at reducing the tool-related vibration exposures, two accelerometers were used to measure vibration both on the subject's hand and on the tool. A tri-axial accelerometer (SENO40F; Larson Davis;

Depew, NY) was attached to the front of the sander using a rare-earth magnet and then the perimeter of the magnet was hot glued to the sander to prevent the accelerometer from rotating. The same sander was used for each subject and it was verified to be in good operating condition as it had been recently maintained by the company. As shown in Figure 3, a second and more sensitive tri-axial accelerometer (3023A2; DYTRAN; Chatsworth, CA) was attached to the back of the subject's hand using tincture of benzoin, a liquid that creates a tacky adhesive and is typically used to help bandages adhere to skin better. The axis of the accelerometer on the hand did not match the axis for the accelerometer on the tool due to the fact that the tool did not have a flat, horizontal surface to place the accelerometer, leaving the axis slightly askew in relation to the hand accelerometer. That is why the vector sum was used as the primary measurement for comparison. The hand was wrapped with a self-adhesive wrap to hold the accelerometer in place on the back of the subject's hand. The accelerometer was positioned on the third metacarpal bone for each subject and the wrap was done while the subject extended the fingers in all directions so that it would not restrict movement during the task. Both accelerometers were connected to an 8-channel data recorder (Model DA-40, Rion; Tokyo, Japan) that simultaneously recorded the tri-axial vibration data at 12,800 Hz from both accelerometers. Because the samples were taken simultaneously the data from the tool-mounted accelerometer was matched directly with the hand-mounted accelerometer, compensating for any changes in the magnitude of vibration that may have taken place during the task.

**Figure 3: Placement of Accelerometer on the hand.**

A 33 m long metal mold referred to as a LM spar was used for the testing and was marked off in 1.2 meter sections.  As can be seen in Figure 4, the spar consisted of a horizontal surface and a vertical surface which formed a right angle with the horizontal surface, a one minute vibration measurement was taken with each glove and the bare hand on both the vertical and horizontal surfaces. In addition, one other sample was taken with the bare hands where the subject placed their non-dominant hand on top of the accelerometer while they used the sander on the horizontal surface.  This was done to see what effect, if any, placing extra pressure on the accelerometer had on the recorded vibration data.  The order that the subject performed the sanding with four gloves and bare hand was randomized and counterbalanced using a Latin square design (Table 2).  The Latin square model ensured that the order that the sanding conditions were tested in was evenly distributed (Table 2). Each glove condition was assigned an arbitrary letter A-E that could be used by the Latin square generator used. For each of the glove conditions six of the subjects started with the horizontal surface first and then did the vertical surface, while the remaining four started with the vertical surface and finished with the horizontal surface.

**Figure 4: An actual LM Spar being sanded by a subject during normal work-day operations.**

**Table 2: Latin Square Model Used in Randomizing the Order of Testing**

| | | Subject Number | | | | |
|---|---|---|---|---|---|---|
| | | 1, 6 | 2, 7 | 3, 8 | 4, 9 | 5, 10 |
| Sample Number | Sample 1 | C | A | B | D | E |
| | Sample 2 | B | C | A | E | D |
| | Sample 3 | A | D | E | C | B |
| | Sample 4 | E | B | D | A | C |
| | Sample 5 | D | E | C | B | A |

Glove A= Proflex 9015; Glove B= Impacto BG401; Glove C = Proflex 910; Glove D = Mechanix M-Pact; Glove E = Bare Hand

As shown in Appendix A, a questionnaire was completed by each subject before the data sampling. The questionnaire collected information on the number of years of experience subjects had working with the tool and the average number of hours per week that they used the tool. After performing the task with the bare hand condition, the subjects were then asked to rate the level of vibration of the tool, and after completing all sanding conditions, rank the gloves in order of perceived effectiveness. When asked to give their years of experience with the tool or the hours per week of use the subject would often give a range of time. In each case the lowest amount was used from this range just to be consistent. As shown in Appendix A, three questions were used for the subject to rate the vibration level which were taken from the scale used by the Department of Labor and Industry from the State of Washington. The first question used a Borg scale of 0-10, 0 being the least amount of vibration 10 heavy vibration, to have the subject rate the vibration level with no reference to any other tools. The second question used the Borg scale as well and had the subject compare that particular sander to other similar tools. The final question used a visual scale to have to subject mark where they thought the vibration level ranked from 0% being the best to 100% being the worst. This part of the questionnaire was administered after the subject had performed the bare hand condition. After all the conditions had been sampled the final part of the questionnaire had the subject rank the gloves from the one they thought reduced vibration the most to the least.

Both of the accelerometers were pre- and post-calibrated using a VC-21 calibrator (VC 21; Metra Mess- und Frequenztechnik; Radebeul, Germany). The calibration data was collected at 12,800 samples per second for at least one minute of vibration time.

**Data Analysis**

For the tool and hand measured vibration data, the logger data was downloaded on the same day as sampling and analyzed using the RION DA-40 Viewer software. First the standard hand-arm vibration frequency weighting filter (Wh) was applied, after which the middle 45 seconds of the 60 second data segment was used to take the frequency weighted average root mean square (RMS) of the magnitude of vibration for each axis. The RMS values were then used to calculate the vector sum vibration measured by each accelerometer. Once the vector sum for each accelerometer was calculated , the transmissibility and the corrected transmissibility was calculated per the ISO 10819 standard for all of the conditions where the gloves were used as shown in equations 1 and 2.

The software program used to evaluate the data was JMP Statistical Discovery Software (version 10.0; SAS Institute; Cary; SC). A p-value of less than 0.05 was used to determine significant differences between groups. To determine if there was a difference in putting hand pressure on the accelerometer, the vector sum values were analyzed using a repeated-measure analysis of variance (RANOVA) and a Tukey follow-up test. Differences between surfaces were also determined using a RANOVA and a Tukey follow-up test, and the order the gloves were tested in was analyzed using a RANOVA as well. The corrected transmissibility and differences between gloves were analyzed using RANOVA and a Dunnett's follow-up test. In the figures the mean, 1$^{st}$ and 3$^{rd}$ quartiles, and standard error are presented unless otherwise noted.

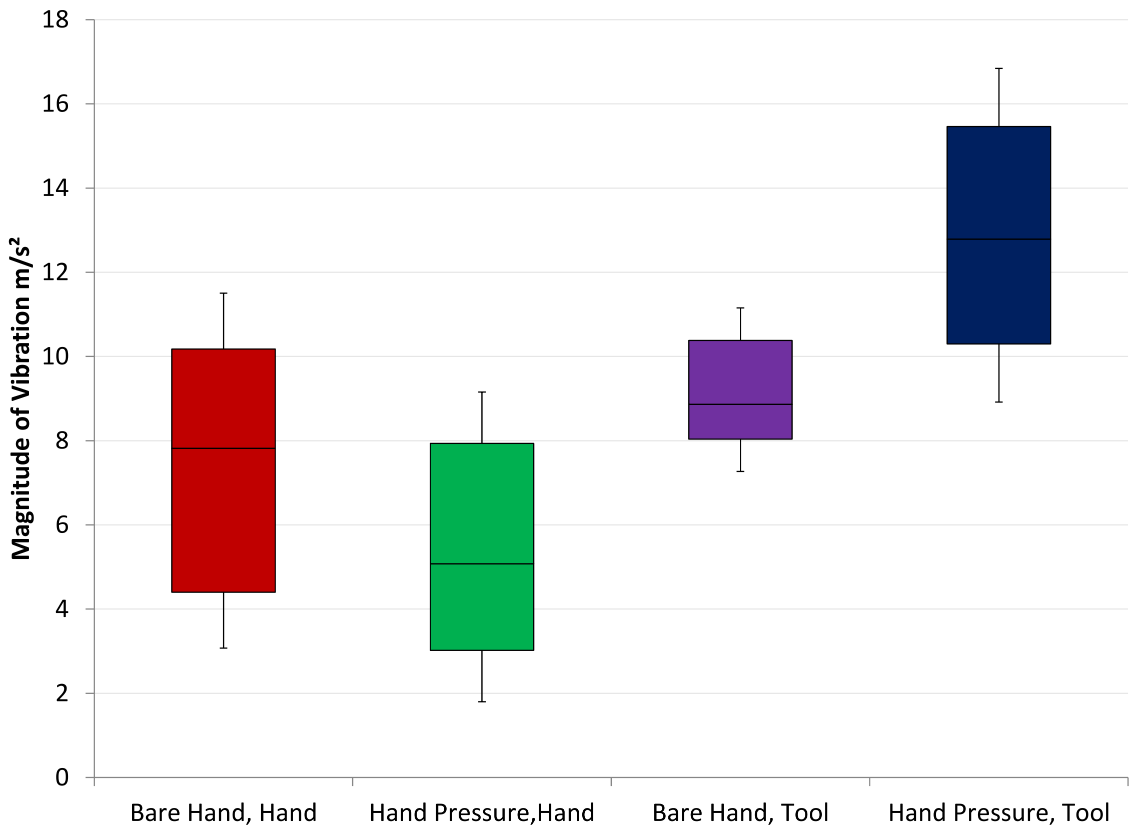
## Results

### Effect of Pressure on the Back of the Hand

In order to determine whether the pressure from the glove that resided over the accelerometer on the back of the hand had any influence on the vibration measurements, the condition where subject put their non-dominant hand on top of the accelerometer on the back of the subject's hand was evaluated. The concern was that, relative to the bare hand condition, putting on gloves would place pressure on the accelerometer, causing a change in the vibration recorded from the back of the hand and that any change in measured vibration, if present, may not be due to any sort of actual increase or decrease in transmission from the tool. By having the subject put excess pressure on the accelerometer with their non-dominant hand, any differences in vibration magnitude or vibration transmission should be apparent when comparing the two bare-hand conditions. Using a repeated measure ANOVA, the two conditions were compared and evaluated to determine whether there were any significant differences between conditions or interaction between the tool and hand-measured vibration. Figure 5 shows the vector sum vibration measured from the tool and the back of the hand under the two conditions. Two subjects did not wish to take the time to perform this particular task and so only data from 8 subjects could be analyzed.

As shown in Figure 5 the placing of the non-dominant hand on top of the dominant hand reduced the magnitude of the vibration measured from the back of the dominant hand ($p = 0.008$) compared to just sanding with the dominant hand alone. In addition, Figure 5 also shows the vector sum vibration measured from the tool, and, in contrast to the hand-measured vibration, the magnitude of tool-measured vibration measured actually increased ($p = 0.002$). The vibration measured on the tool most likely increased due to the extra pressure put on the tool with the non-dominant hand on top of the hand using the tool. Since the vibration measured at the hand decreased while the vibration measured at the tool increased, it appears that the pressure added to the hand may be representative of the effect of the pressure added by the glove to the hand mounted accelerometer, should not cause the corrected transmission (CT) to be underestimated.  In fact it would appear to be more likely to overestimate the protective factor of the gloves.

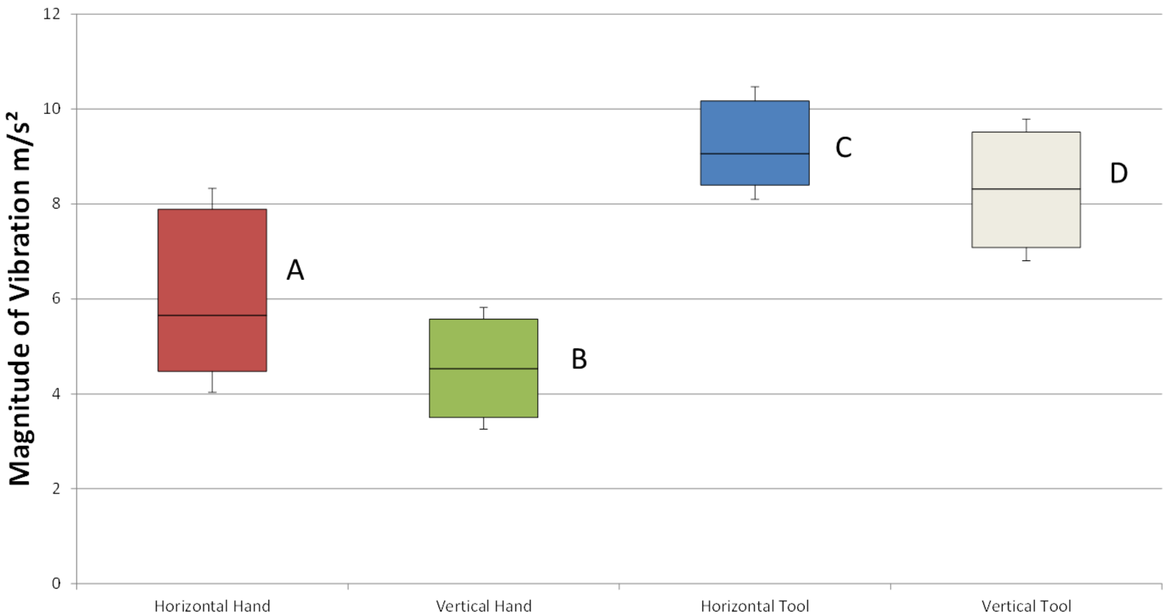
**Figure 5: Hand Pressure on Accelerometer Plot (n=8). The measurements from both the tool and the hand were all significantly different.**




**Effect of Surface Orientation: Horizontal versus Vertical**

Pilot testing of the task had suggested that there would be differences in the amount of tool-measured vibration between the horizontal and vertical surfaces.  The effect of surface orientation was tested using a RANOVA methods, and as can be seen in figure 6, the vector sum vibration collected from both the tool and the hand were significantly higher when using the sander on the horizontal surface ($p = 0.01$).  The Tukey follow-up test results, results shown by the letters in figure 6, indicated all values between the horizontal and vertical surfaces were significantly different in regard to the magnitude of vibration measured on the tool and from the back of the hand and tool. Figure 7 shows that the differences between surfaces from the vector sum at the hands had more variation with the padded, fingerless glove as well as the bare hand. The tool vector sum in figure 8 shows a consistent difference between surfaces. This led to the conclusion that all further evaluation of the gloves needs to be done in regards to which surface was tested.

**Figure 6: Surface Vector Sum Comparison Plot (n=10). All of the gloves were significantly different from one another.**




*Plots not connected by the same letter are significantly different

**Figure 7: Hand Vector Sum Surface Comparison Plot (n=10). The surfaces were significantly different from each other.**

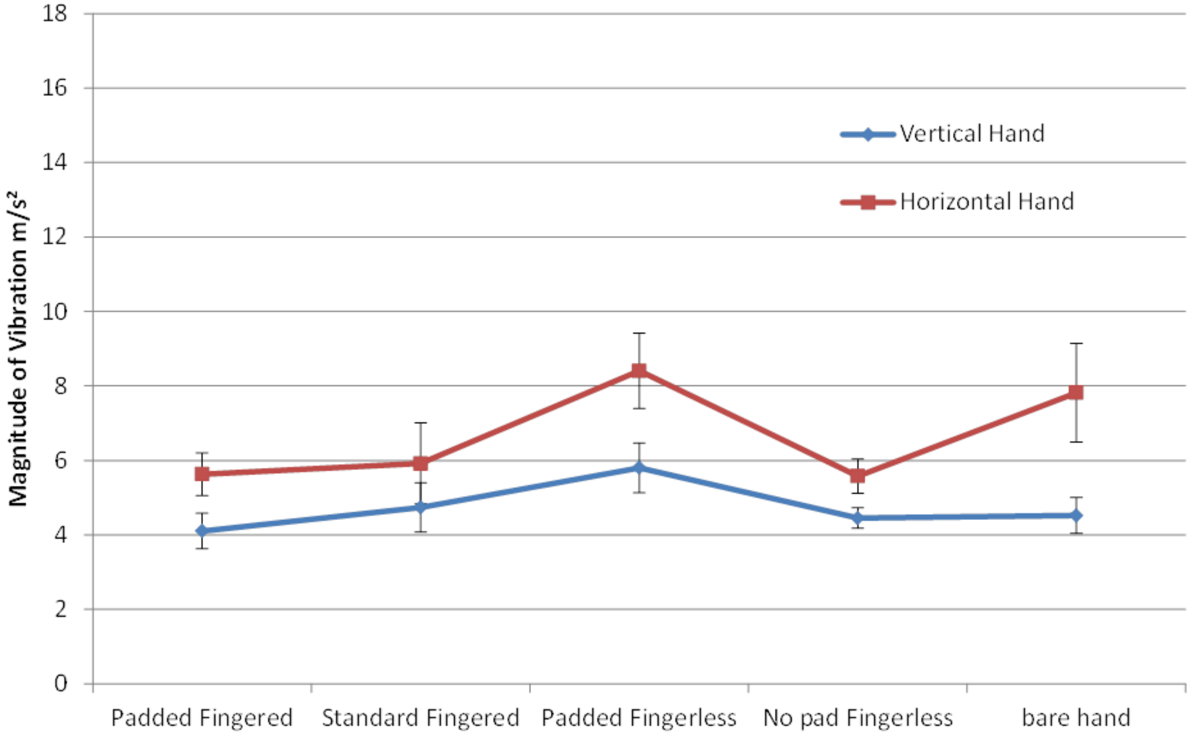
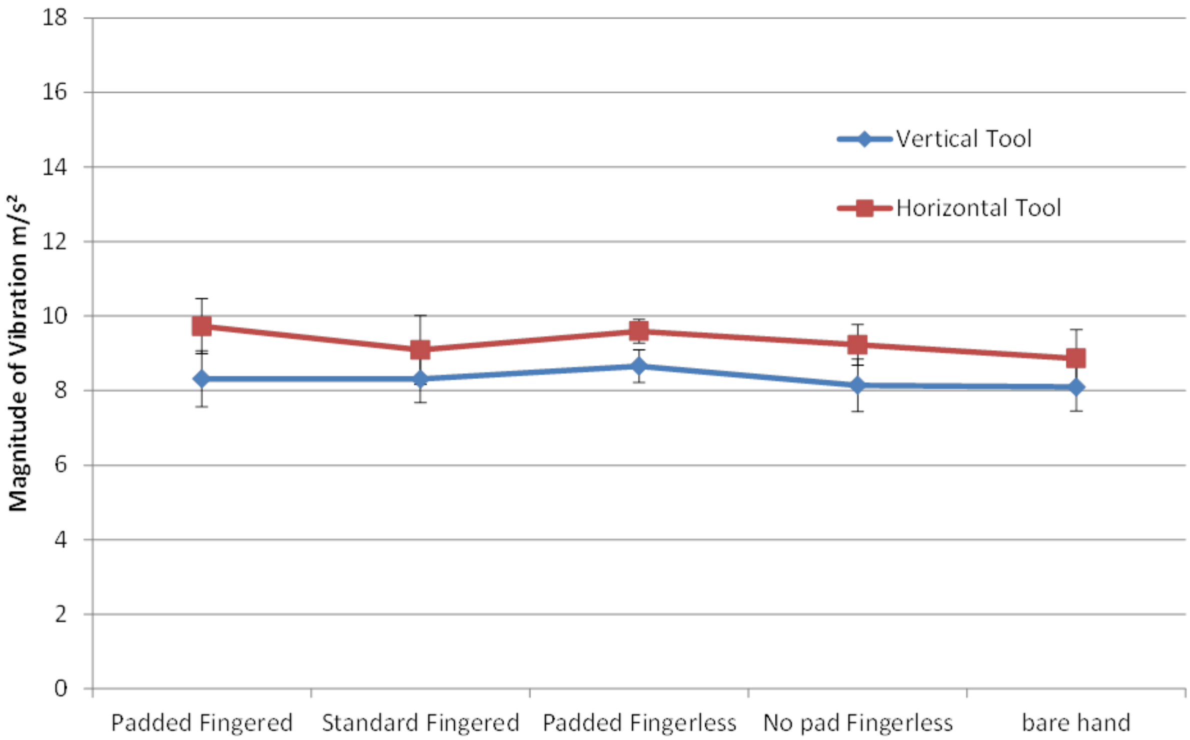



**Figure 8: Tool Vector Sum Surface Comparison Plot (n=10). The surfaces were significantly different from each other.**



**Effects of the Sampling Order**

In order to determine if there was any significant effect in the order that the samples were taken a RANOVA was used to analyze the vector sum of both the surface-dependent order and the surface-independent order. There was no significant effect in either analysis (p=0.80 surface-dependent, p=0.83 surface-independent). The results are displayed in figures 9-12.

**Figure 9: Horizontal Surface-Dependent Sampling Order (n=10).**

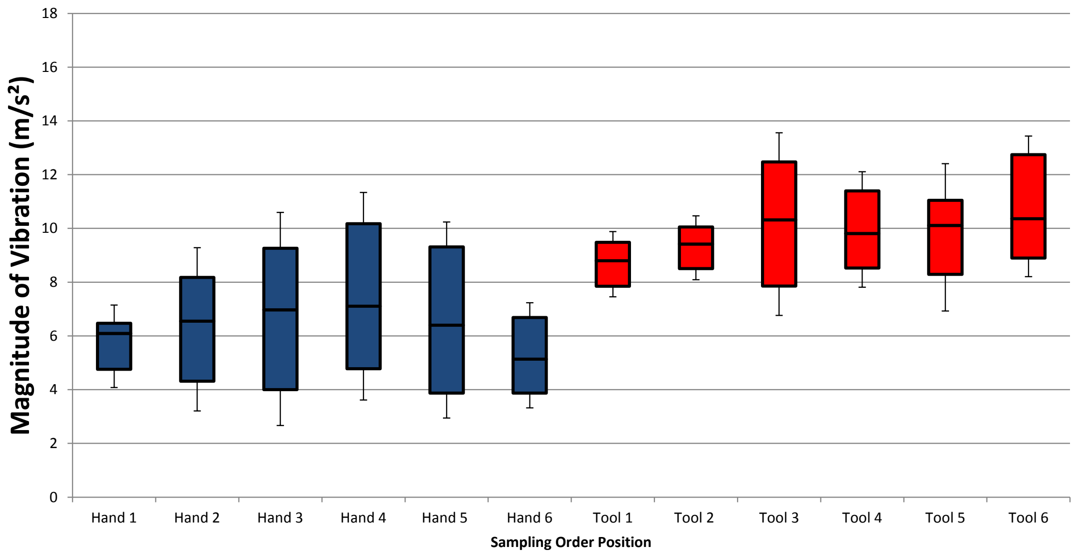


**Figure 10: Vertical Surface-Dependent Sampling Order (n=10).**

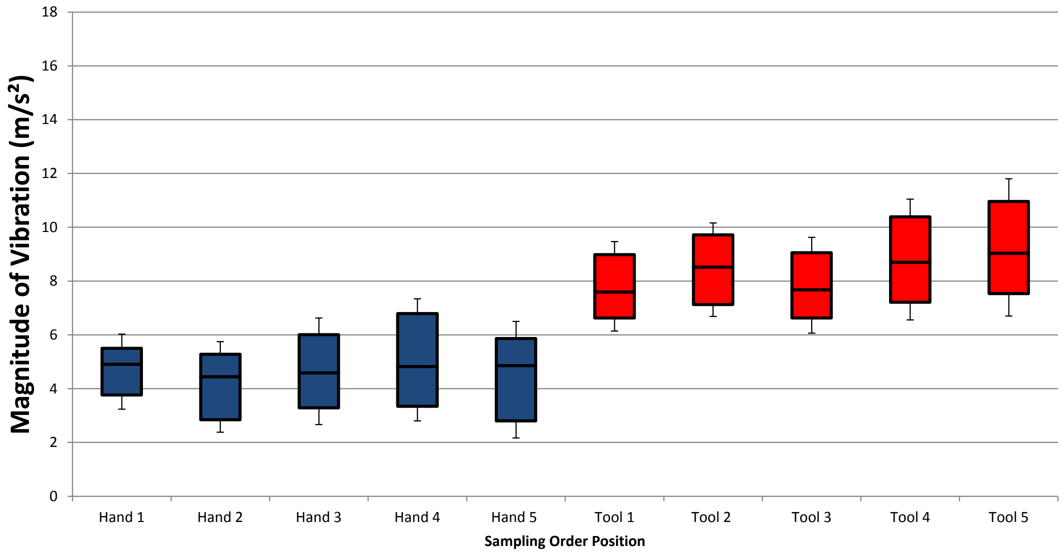



**Figure 11: Hand Surface-Independent Sampling Order (n=10).**

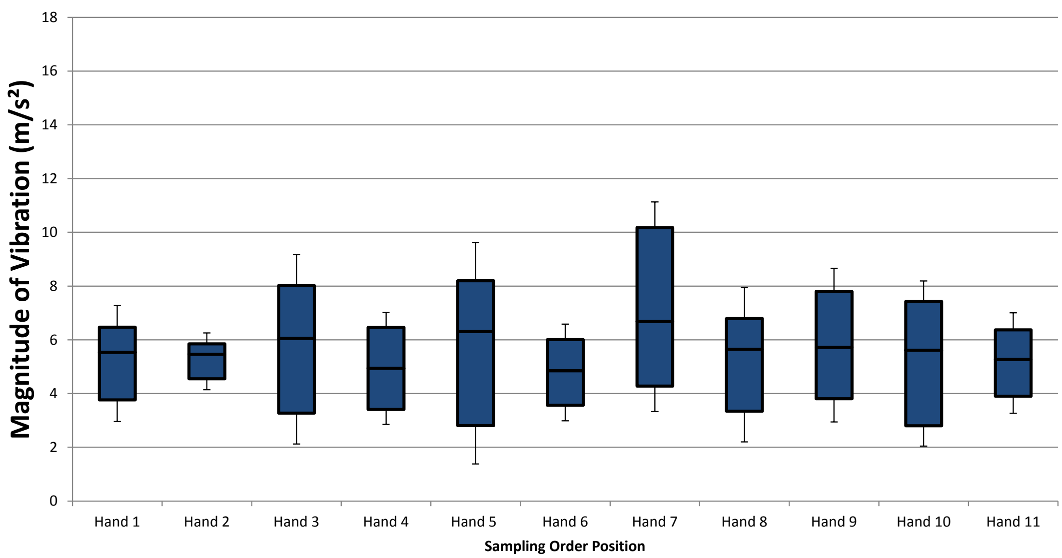
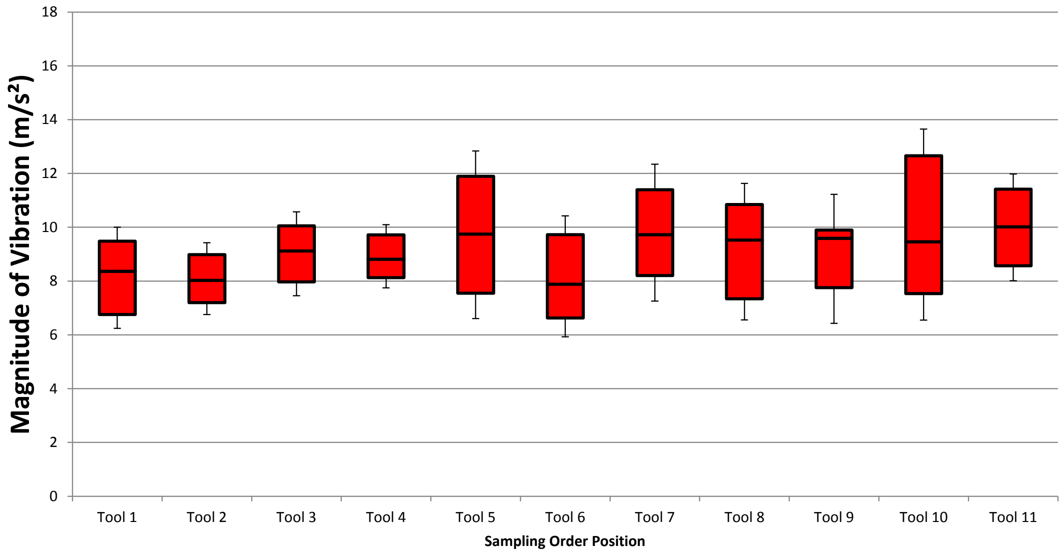


**Figure 12: Tool Surface-Independent Sampling Order (n=10).**




## Corrected Transmissibility

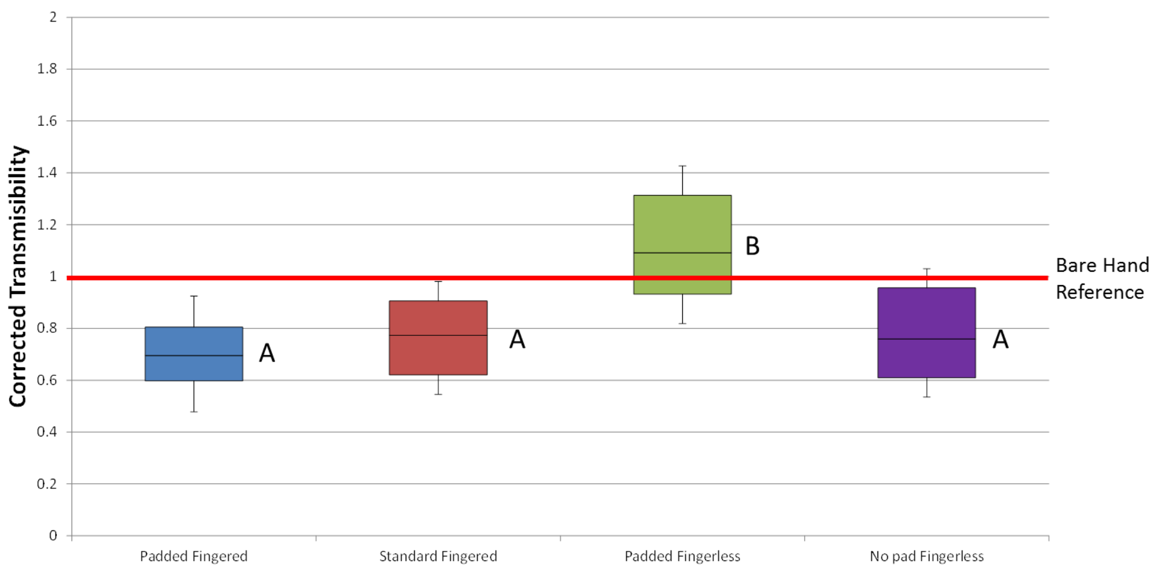
After identifying that the order in which the gloves were tested and added glove pressure were not confounders the CT was analyzed using RANOVA methods. As shown in figure 13, the CT results from the horizontal surface showed that there was a significant difference between the gloves ($p = 0.004$) and the padded, fingerless glove was significantly different than the rest and amplified the vibration exposure. However, when the corrected glove transmissibilities were compared to the control value of 1 (no amplification or attenuation by the glove), the Dunnett's follow-up test indicated that none of the gloves CT were significantly different from a control value 1. As Table 3 shows, some of the CT's were close to being different than 1 and likely would be different with a larger sample size. JMP was used to perform a power analysis and with the sample sized used for the horizontal surface with the current subjects the power was 0.614, that there was about a 61% chance that an existing significant difference would be detected. In order to increase the power to 0.8, 58 samples are needed.

**Table 3: Dunnett's Test of the CT's from the Horizontal Surface Indicating either Significant Attenuation or Amplification of the Vibration by the Gloves (n=10)**

| Glove | Difference | p-Value |
|---|---|---|
| Padded Fingerless | -0.17 | 0.83 |
| Standard Fingered | -0.04 | 0.11 |
| No pad Fingerless | -0.02 | 0.07 |
| Padded Fingered | -0.01 | 0.07 |

.

**Figure 13: Glove CT Horizontal Surface Plot (n=10). None of the gloves were significantly different than one, but the padded, fingerless glove was significantly different from the other 3.**

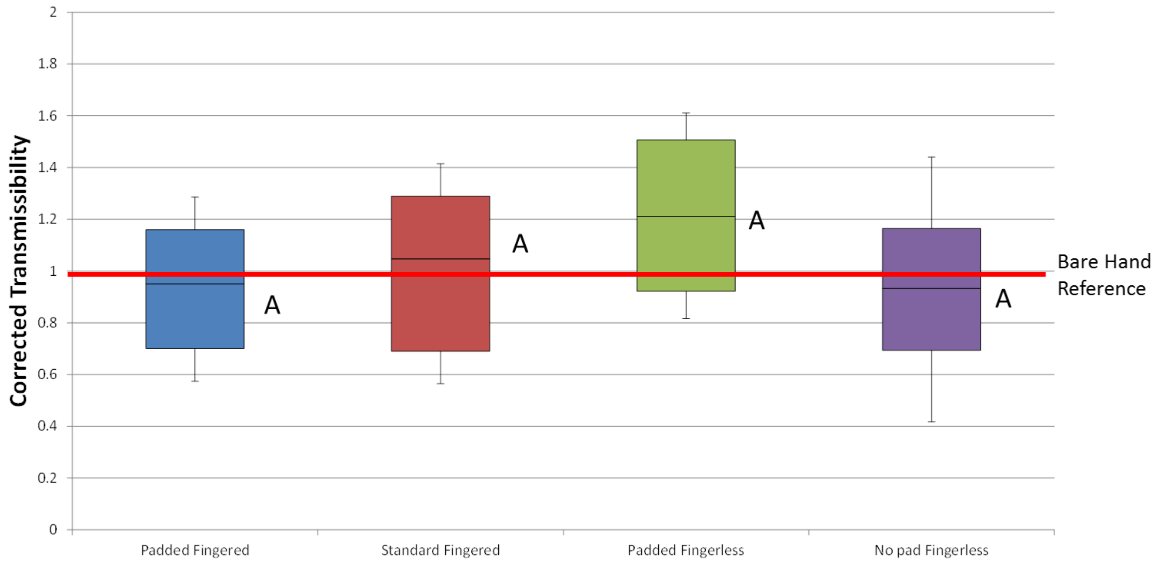



When the gloves were used on the vertical surface, shown in Figure 14, there were no differences in CT between gloves and the CT's were all higher relative to the CT's measured from the horizontal surface. In addition, as shown in Table 4, the Dunnett's follow up tests indicated that none of the CTs were significantly different than the control value of 1. The power analysis for the vertical surface was far weaker than the horizontal one, with a power of 0.142. There lower power is due to a higher standard deviation found in all of the glove samples. In order to increase the power to 0.80 it would take 237 samples. This is much greater than the horizontal surface and it would be difficult to find enough subjects to participate.

**Table 4: Dunnett's Test of the CT's from the Vertical Surface Indicating either Significant Attenuation or Amplification of the Vibration by the Gloves (n=10)**

| Glove | Difference | p-Value |
|---|---|---|
| Padded Fingerless | -0.32 | 0.70 |
| No pad Fingerless | -0.35 | 0.81 |
| Standard Fingered | -0.48 | 1.00 |
| Padded Fingered | -0.48 | 1.00 |

**Figure 14: Glove CT Vertical Surface Plot (n=10). None of the gloves were significantly different than 1.**




The RANOVA, shown in figures 15 and 16, also shows that there are no interactions by subject across the different gloves.

**Figure 15: Horizontal Glove by Subject Interaction (n=10). There was no significant interaction between glove and subject.**

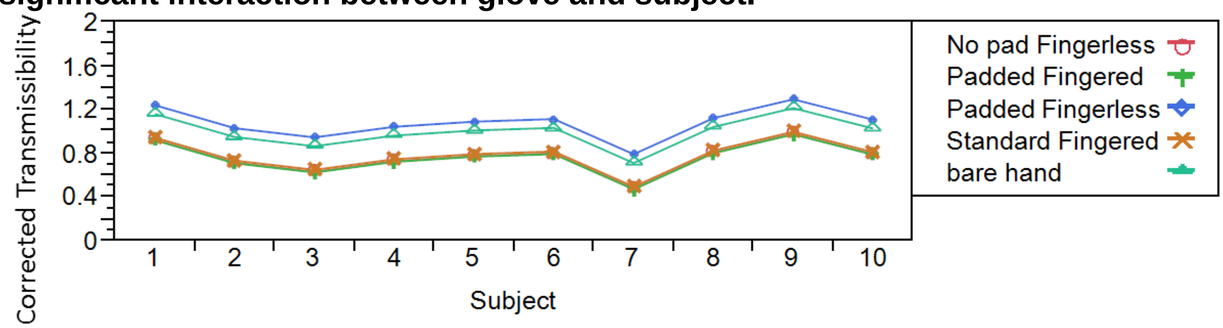
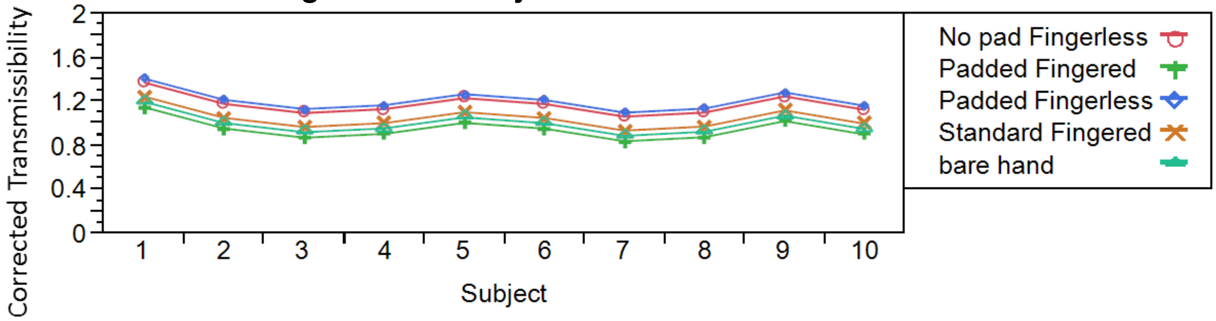


**Figure 16: Vertical Glove by Subject Interaction (n=10). There was no significant interaction between glove and subject.**




### Subject Perception of Vibration Reduction

Finally, each of the subjects filled out a questionnaire that asked them to rate the gloves in order of which they thought reduced vibration from the best to the worst. The subject's responses were analyzed using a chi square test. According to the analysis, the standard fingered glove was ranked the most effective while the unpadded, fingerless glove was ranked the least effective. The padded, fingerless glove performed the worst in the actual test but it was ranked as the second most effective glove. Table 5 shows the overall results and rankings. The chi square test showed that there was a difference in the ranking of the gloves (p = 0.001) and further test showed that the standard fingered glove and the padded fingerless gloves were rated significantly higher than the other two sets of gloves.

**Table 5: Subject Glove Ranking. 1 was the best ranking a glove could receive and 4 was the worst; the lower the mean the less vibration was perceived by the subjects.**

| Glove | | | | Mean Rank |
|---|---|---|---|---|
| Unpadded Fingerless Rank | A* | | | 2.8 |
| Padded Fingered Rank | A | B | | 2.6 |
| Padded Fingerless Rank | | B | C | 2.2 |
| Standard Fingered Rank | | | C | 1.9 |

*Gloves not sharing the same letter are perceived as significantly different.

Appendix A also shows the two the Borg scale questions that were used to gather information from the subjects on their subjective perceptions of the magnitude of the tool-transmitted vibration. The two different Borg Scale questions were used to identify how the subjects rated the amount of vibration from the orbital sander without reference to other tools and the amount of vibration from the orbital sander relative to other vibrating tools they use in their daily work. The scale was from 0-10 with 0 being no vibration and 10 being the most vibration. The Borg questions were completed after the condition where the subject used the orbital sander with their bare hand. The Borg vibration level rating with no reference to other tools had a mean of 7.2 (Std Dev 2.3). When the subjects were asked to rate the tool in reference to similar tools that they had used previously during their regular work the mean dropped down to 6.5 (Std Dev 2.3). The final question asked the subject to rate the tool using a visual scale from 0% (best) – 100% (worst) in reference to similar tools they had used previously. In this part the mean rating was 51% (Std Dev 0.3).

**Table 6: Borg Scale Responses (n = 10). When the scale was used in reference to other tools, the mean value was lower than when no reference was used. Using a visual reference scale also lead to lower values and a less variability among subject responses.**

| Information | Mean) | Std Dev | Min | Max | Std Err | Median |
|---|---|---|---|---|---|---|
| Borg w/out Reference to other tools | 7.25 | 2.3 | 4 | 10 | 0.41 | 6.5 |
| Borg w/Reference to orbital sander | 6.5 | 2.3 | 3 | 10 | 0.40 | 6 |
| Visual Reference, 0% (best) t0 100% (worst) | 51% | 0.3 | 20% | 100% | 10% | 45% |

## Discussion

### Glove Effectiveness

There was a significant interaction found between the vector sum and the surface being sanded. This interaction confirmed that each further analysis to be done in regards to which surface was being tested. The corrected transmissibility analysis of the horizontal surface revealed a significant difference between gloves, but no significant difference in relation to a reference of 1, meaning no reduction/amplification of vibration. This means that while we are unable to reject the first null hypothesis with this study sample, we can reject the second null hypothesis. We can reject the second null hypothesis because for some reason, the padded, fingerless glove is amplifying the vibration levels. This result has been noted previously that when a handle was programmed to imitate vibration spectra of different tools there were a number of gloves that would amplify vibration on specific tools (Griffin, 1998). The gloves were fingerless, so it may be that the subject had more exposure directly to the vibration, or it may be that the type of air-cell padding used in the glove resonated with the frequencies of vibration given off by the sander. It is also likely that if there had been a larger population the three other gloves' CT would have been significantly lower than the reference value of 1 for the horizontal surface.

However, none of the gloves appear to have a significant effect while the subject is working on a vertical surface. There is no significant difference between the gloves' CT on the vertical surface between themselves, nor is there a significant difference between the gloves and a reference value of 1. In regards to the vertical surface the results indicate that the first and second null hypotheses cannot be rejected. The reason that the vertical surface does not have a significant difference between gloves and the horizontal does is probably due to the way that the subjects grip the sander during that part of the task. While working on the vertical surface, the subject uses mostly finger strength to grip the sander and the palm of the hand has very little contact with the tool. Also, the amount of force applied to the tool, and from the tool to the surface, for the different surfaces also varies. The subject has to apply force not only into the surface, but also against gravity in order to sand the vertical surface. It is possible that the reduced surface area contact as well as the varying amount of force exerted affect the gloves' performance.

From the results of the analysis it would appear that the padded, fingerless glove is the only one to not significantly reduce vibration while the subject is working on a horizontal surface. The three other gloves give a similar mean reduction in vibration from 21.6-24%. In the case of the horizontal surfaces, none of these gloves would have met the 40% reduction required by ISO 10819 to be labeled as "anti-vibration" gloves. In the Griffin study that used a handle to imitate the different tool vibration frequencies similar results were obtained. Only 3 of 10 gloves provided any sort of significant reduction (Griffin, 1998). This previous study also noted that the gloves usually were only able to attenuate the higher frequency vibrations and were ineffective with the mid-range frequencies that are more heavily weighted in measuring HAV. Another study that was looking at the use of glove effectiveness on grinders and chainsaws saw that some gloves were effective at reducing vibration from grinders by as much as 46%, but that the rest showed only a 30% reduction. For chainsaws, there was only a maximum reduction of 23%, most likely due to the lower frequencies produced by the chainsaw (Pinto, N, Bovenzi, Paddan, & Griffin, 2001). Both of these studies indicate that glove performance is highly dependent on what type of tool is being used.

With little or no significant difference between the gloves, it raises an interesting point of cost-effectiveness. The cost of the thickly padded Proflex 9015 usually runs from $50-60 the Mechanix glove can usually be found for $25-35. The Mechanix, being thinner, probably gives the subject more dexterity and sensitivity than the Proflex 9015, requiring less force from the subject to complete the task. While a full cost-benefit analysis would need to be done to verify this, it is possible that buying the Proflex 9015 instead of cheaper gloves may not have any significant benefits when used for this type of task. Also, when you take into account that a good portion of the task is done on the vertical surface, it becomes very uncertain that any of the gloves provide a significant benefit to the subject. This is especially true when you take into account that when using gloves, especially the thicker ones, the subject may have to use more force when handling the sander, which could in turn lead to other musculoskeletal problems.

**Subject Evaluations of Gloves**

There was a significant difference between the subject rankings of the gloves. The standard, fingered glove was ranked significantly higher than all the other gloves except the padded, fingerless glove. While the standard, fingered glove was ranked higher than the padded, fingerless glove, the difference was not quite significant. Because the padded, fingerless glove did so well in the subject rankings yet performed the worst out of all the gloves, the third null hypothesis, that the subjects' perception of vibration reduction does not match the measured vibration reduction, cannot be rejected. Similar studies have noted that employee preference does not particularly match with laboratory or predicted results (Pinto, N, Bovenzi, Paddan, & Griffin, 2001). Other factors such as flexibility, material, and thermal retention may influence a subject's preference.

It is very possible that a loss of dexterity and sensitivity contributed to the lower rating that the padded, fingered glove received in the questionnaire. The data would seem to indicate that the padded, fingered glove seems to give the most protection to the employee, it was only deemed to be the third most effective glove overall. The glove may have been harder to use or less comfortable and this may have caused the subjects to subconsciously rate them worse than the other gloves. The padded, fingerless glove, which performed the worst, was highly rated by workers. Subject perception of vibration does not appear to be a good indicator of glove effectiveness.

**Limitations of this Study**

One of the biggest limitations of this study was the small sample size (n=10). This was due to the practical limitations of the number of employees at the worksite qualified to perform the task. A larger sample size would likely change some of the glove corrected transmissibilities which were borderline insignificant to become significantly different, notably on the horizontal surface. Using the data from this study, a sample size of n=88 would give a power of 0.95. It is within reason that 88 samples could be found to participate in a study. Unfortunately the vertical surface was much more variable and in order to gain statistical power of 0.95 the sample size would have to be n=533. It could prove to be very difficult to find that many subjects that qualify to participate in this type of study.

Another limitation was that this was an older population of highly experienced workers familiar with the task. The results may not be generalizable to a younger population, or one with little to no experience using a sander. Older subjects may have different work practices such as applying less force to the sander, reduced grip force, and reduced tactile sensitivity due to the effects of aging or from long-term exposure to HAV.

Another serious limitation of the study was that there was no frequency analysis performed and that the grip-forces of the subjects were not measured. It has been shown that frequency can have a large effect on grip-force (Radwin, Armstrong, & Chaffin, 1987). Different frequencies can cause the subject to grip the tool more tightly. As the subject grips the tool more tightly, more vibration is transmitted into the hand. Because no measurements were taken to measure the grip-force of each subject it is unclear what effect it played overall and intra-subject variability of grip force for the different glove conditions cannot be accounted for. However, each subject's measurements were only compared to their own baseline sample, so any inter-subject variability did not affect the results. Also, the different types of materials that the gloves were made of may not have reduced the same frequencies of vibration. The Wh weighting filter was used to account for the frequencies that in theory are the most harmful to humans, however, it is possible that some of the gloves did a better job of eliminating frequencies that were not taken into account. Considering the current controversy regarding the use of the Wh filter, it would be good to gather more information on what specific frequencies are being affected the most.

**Future Work**

One of the first steps should be to get a larger sample size in order to increase the power of the study. Also, an octave band analysis should be done to determine what frequencies are being reduced and which, if any, are being amplified. Each glove could be analyzed to determine differences and similarities in the octave band analysis between the gloves looking at material, construction, and overall design.

Further study could also be done to determine what adverse health effects are actually occurring from orbital sanders during this type of work. It is difficult to separate what damage is being done directly by work-related vibration exposure as opposed to outside sources. However, until the severity of damage caused by these tools can be determined it is unclear whether further research is beneficial. It is possible that the current strategies usually put in use such as work rotations, tool maintenance, and mandatory breaks, may be effective at preventing HAVS.

## Conclusion

This method attempted to analyze the effectiveness of gloves in reducing vibration, to see which of the gloves perform the best, and identify if the subjects' preferences matched with the actual results. It would appear that some of the gloves have a very small reduction in vibration when the task is done on a horizontal surface and the majority of the contact with the tool is with the palm. However, when the grip on the tool changes and the palm loses contact the gloves appear to have no significant effect. At least one glove appears that it may amplify the magnitude of vibration transmitted to the subject. This study would suggest that while a glove may pass the anti-vibration ISO 10819 qualifications it may not actually be effective for different tools and tasks.

## Works Cited

*Worried about your hands?* (2011). Retrieved from Health and Safety Executive: http://www.hse.gov.uk/vibration/hav/yourhands.htm

ACGIH. (2012). TLVs and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. Cincinnati, OH: ACGIH.

Alaska Department of Labor and Workforce Development. (2013). *Physical Agent Data Sheet - Hand-Arm Vibration*. Retrieved from Labor Standards and Safety Division: http://www.labor.state.ak.us/lss/pads/hand-arm.htm#Preventing Hand-Arm Vibration Diseases

Bovenzi, M. (1998). Exposure-Response Relationship in the Hand-Arm Vibration Syndrome: an overview of current epidemiology research. *Int Arch Occup Environ Health*, 509-519.

Brammer, A. J., Taylor, W., & Lundborg, G. (1987). Sensorineural stages of the hand-arm vibration syndrome. *Scandinavian Journal of Workplace Environmental Health*, 279-283.

Brammer, A., & Taylor, W. (1982). *Vibration Effects on the Hand and Arm in Industry.* Wiley.

Dong, R. G., Welcome, D. E., McDowell, T. W., Wu, J. Z., & Schopper, A. W. (2005). Frequency weighting derived from power absorption of fingers-hand-arm system under Z-axis vibration. *Journal of Biomechanics*, 2311-2324.

Dong, R., McDowell, T., Welcome, D., Smutz, W., Schopper, A., Warren, C., . . . Rakheja, S. (2003). On-the-hand measurement methods for assessing effectiveness of anti-vibration gloves. *32*(4).

Farkkila, M., Pyykko, I., Korhonen, O., & Starck, J. (1979). Hand grip forces during chain saw operation and vibration white finger in lumberjacks. *36*, 336-341.

Griffin, M. J. (1998). Evaluating the effectiveness of gloves in reducing the hazards of hand-transmitted vibration. *Occupational and Environmental Medicine*, 340-348.

Hewitt, S. (1998). Assessing the performance of anti-vibration gloves -- a possible alternative to ISO 10819. *Annual Occupational Hygenist*, 245-252.

House, R., Wills, M., Liss, G., Switzer-McIntyre, S., Manno, M., & Lander, L. (2009). Upper extremity disability in workers with hand-arm vibration syndrome. *Occupational Medicine*, 167-173.

International Organization for the Standardization. (1996). mechanical vibration and shock--hand-arm vibration--method for the measurement and evaluation of the vibration transmissibility of gloves at the palm of the hand. *ISO 10819*. Geneva.

OSHA. (2008, 6 24). *OSHA Technical Manaul.* Retrieved from OSHA.gov: https://www.osha.gov/dts/osta/otm/otm_ii/otm_ii_3.html#vibration_monitors

Palme, K., Griffin, M., Syddal, H., Pannett, B., & Coggon, D. (2000). Prevalence and pattern of occupational exposures to hand transmitted vibration in Great Britain: findings from a national survey. *Occupational and Environmental Medicine*, 218-228.

Palmer, K., Griffin, M., Syddall, H., Pannett, B., Cooper, C., & Coggon, D. (2001). Risk of hand-arm vibration syndrome according to occupation and sources of exposure to hand-transmitted vibration: A national Survey. *American Journal of Industrial Medicin*, 389-96.

Pinto, I., N, S., Bovenzi, M., Paddan, G., & Griffin, M. (2001). *Protection effectiveness of anti-vibration gloves: field evaluation and laboratory performance assessment.* EC Biomedd II Concerted action BMH4-CT98-3291.

Pitts, P., Mason, H., Poole, K., & Young, C. (2011). Relative Performance of Frequency Weighting W sub(h) and Candidates for Alternative Frequency Weightings When Used to Predict the Occurrence of Hand-Arm Vibraiton Induced INjuries. *Canadian Acoustics*, 96-99.

Radwin, R., Armstrong, T., & Chaffin, D. (1987). Power hand tool vibration effects on grip exertions. *Ergonomics*, 833-855.

Rakheja, S., Dong, R., Welcome, D., & Schopper, A. (2002). Estimation of tool-specific isolation performance of anti-vibration gloves. *International Journal of Industrial Ergonomics*, 71-87.

Stoyneva, Z., Lyapina, M., Tzvetkov, D., & Vodenicharov, E. (2003). Current Pathophysiological views on vibration-induced Raynaud's phenomenon. *Cardiovascular Research*, 615-624.

Taylor, W. (1988). Hand-arm vibration syndrome: a new clinical classification and an updated British standard guide for hand transmitted vibration. *British Journal of Industrial Medicine*, 281-282.

# Appendix A: Sampling Questionnaire

## Part 1

Worker Number:

Have you used other tools of this type before: yes / no

Number of years working with this type of tool: ________________

On average, how many hours per week do you use this tool? ____

## Part 2 (completed after the bare hand condition)

*Could you please rate the vibration level when you were using this tool? 0-10*

*Have you used other similar tools before? If yes, comparing to similar tools that you have used before, what would you rate the vibration level of this particular tool? 0-10*

*What do you think about the vibration level of this particular tool comparing to other similar tools that you have used? Please use the scale as shown.*

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0% (best) | | | 25% (much better) | | | 50% (about average) | | | 75% (much worse) | | | 100 % (worst) |

## Part 3

Glove Type____ Horizontal RION File #____ Vertical RION File #____

Glove Type____ Horizontal RION File #____ Vertical RION File #____

Glove Type____ Horizontal RION File #____ Vertical RION File #____

Glove Type____ Horizontal RION File #____ Vertical RION File #____

Glove Type____ Horizontal RION File #____ Vertical RION File #____

Glove Type____ Horizontal RION File #____ Vertical RION File #____

Glove Type____ Horizontal RION File #____ Vertical RION File #____

Rank the gloves in order from the best at reducing vibration to the worst: