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Hand-Arm Vibration Controls for Jackleg Rock Drills: A Pilot Study Assessing Ergonomic Hazards

Ciara Kremer[1], **Daniel Autenrieth**[1], **Theresa Stack**[1], **Scott Rosenthal**[2], **Dave Gilkey**[1,*]

[1]Department of Safety, Health and Industrial Hygiene, Montana Technological University, Butte, Montana 59701

[2]Department of Mining Engineering, Montana Technological University, Butte, Montana 59701

Abstract

Jackleg drill operators are exposed to harmful levels of hand-arm vibration (HAV). Anti-vibration handles and gloves provide modest reductions in HAV exposures and forearm muscle exertion from the use of AV handles and gloves by jackleg drill operators. The goal of this pilot study was to investigate changes in HAV with the use of anti-vibration gloves and handles compared to forearm muscle exertion experienced by operators and measured with surface electromyography (EMG). Five subjects operated the drill under four different cases: no anti-vibration controls, anti-vibration gloves only, anti-vibration handle only, and simultaneous anti-vibration handle and glove use. Muscle exertion was expressed as a percent of maximum voluntary contraction (%MVC) and was compared using Welch's ANOVA with Games-Howell post-hoc comparisons. The case with both anti-vibration controls in use simultaneously (largest grip diameter) was associated with a mean %MVC of 36.13% during operation for all forearm muscles combined, which was significantly higher than the other cases ($p < 0.05$). There were no statistically significant differences in mean HAV exposures. The anti-vibration handle with anti-vibration glove case only increased the maximum allowable exposure time by eight minutes as compared to the control case without any anti-vibration controls. These results suggest that the modest HAV exposure reductions from the use of anti-vibration handles and gloves may pale in comparison to the increased muscle exertion resulting from their use, and this tradeoff among jackleg drill operators is a potential concern that warrants further investigation.

Keywords

hand arm vibration; mining ergonomics; work related musculoskeletal disorder; jackleg drill

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[*]Corresponding author: dgilkey@mtech.edu; Tel: +1-406-496-4895.

Author Contributions: Ms. Ciara Kremer, lead author was the graduate student earning her MS degree. Dr. Autenrieth was Chair of the graduate committee and oversaw the study from conception to completion. Professor Stack was a graduate committee member and contributed to all phases of the study. Professor Rosenthal was a graduate committee member and participated in all phases of the study. Dr. Gilkey contributed to the interpretation of the findings and provided detailed review, editing, manuscript preparation and submission.

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Introduction

The jackleg drill with a pneumatic pusher leg that combines percussion and rotation to drill rock is a commonly used tool in underground mining operations. Jackleg drills can produce sustained hand-arm vibration (HAV) acceleration of as much as 25 m/s^2 across the 6.3-1250 Hz frequency range [1]. Exposures in this frequency range have been associated with hand arm vibration syndrome (HAVS) [1]. The National Institute for Occupational Safety and Health (NIOSH) reported that 100,000 miners were potentially exposed to vibration by pneumatic drills within the United States [2] The NIOSH also reported a direct relationship between years exposed to pneumatic drilling and severity of HAVS [2]. NIOSH researchers estimated a 50% or greater prevalence of HAVS work related musculoskeletal disorder (WRMSD) among the 1.25 million American workers who use vibration tools [2]. There is an estimated 144,000 workers in the US and Canada with HAVS symptoms from vibration injury [3]. Short-term exposures as little as two to 16 minutes in the 31.5 to 125 Hz range were found to reduce vibrotactile sence [4]. A study by Malchaire and collegaes found that exposure to 31.5, 125 and 500 Hz for 32 minutes resulted in loss of vibration perception threshold [5]. Another study also found that short-term expousre to frequencies 31.5, 125, and 500 Hx for 32 minutes was found to alter normal vibration perception threshold and resulted in paraethesisas and numbness [5].

The American Conference of Governmental Industrial Hygienists (ACGIH), recommends that daily vibration exposure should not exceed 5 m/s^2, with an Action Limit of 2.5 m/s^2, as an eight-hour, frequency-weighted acceleration sum [6]. The NIOSH [2] and ACGIH [6] reported that gloves may reduce HAV in higher frequencies. [6]. It has been reported that AV handles can reduce vibration acceleration up to 50% between the handle-hand interface [1]. AV gloves are often made of a vibration dampening material such as air bladders [7] or viscoelastic materials [8]. The AV material is placed between the hand and the handle resulting in a larger grip diameter for the worker. For a worker to maintain the same grip force, while using a larger than optimal grip diameter, an increase in forearm muscle exertion is required [9]. Maximum grip strength has been shown to decrease an average of 39% for each 10 mm increase in handle diameter away from a worker’s optimal grip diameter [9].

The implementation of AV controls should not introduce new hazards, such as additional forearm muscle stress and strain due to larger handle diameter. Anecdotal reports from miners and mining engineers suggests that training with jackleg drills were associated with discomfort when combining the AV handles and gloves. Taking this into consideration, an investigation into AV jackleg drill handles and gloves in underground mining was warranted. The purpose of this pilot study was to investigate HAV exposure and forearm muscle exertion among jackleg drill operators in four cases, listed in order of increasing grip diameter: 1) a traditional jackleg drill handle without an AV glove, 2) a traditional jackleg drill handle with an AV glove, 3) an AV jackleg drill handle without an AV glove and 4) an AV jackleg drill handle with an AV glove.

The following hypotheses were established for this pilot study as a way to evaluate the potential tradeoff between HAV reductions from AV glove and handle use as compared to potential increase in forearm muscle exertion from increased grip diameter:

$H_{o1:}$ The null hypothesis was that changes in grip diameter would not effect forearm muscle exertion when operating a jackleg drill. The alternative hypothesis was that there would be a difference in mean forearm muscle exertion when exposed to different grip diameters.

$H_{o2:}$ The null hypothesis was that there would be no difference in HAV exposure among jackleg drill operators from the use of AV handles and/or AV gloves. The alternative hypothesis was that there would be a difference in HAV exposures among the different handle/glove cases.

Materials and Methods

Location and Study Population

The study was conducted at the Orphan Boy Mine, a historical underground silver mine owned by Montana Technological University. One of the requirements for Mining Engineering students is to take an underground mining practicum course, where among other things, the students experience hands-on use of mining equipment including the jackleg drill. Each of the students get opportunity to use jackleg drill for approximately 3 to 5 minutes. Participants were recruited from the spring semester of 2019. A total of five right-handed male subjects participated in this study. Participation was voluntary and did not influence participant's grade. Subjects with a history of hand or forearm injury were excluded, as well as subjects who identified as left handed or ambidexterious. The protocols for this study were approved by The University of Montana Instititutional Review Board.

Equipment

Two jackleg drills (Model MWS83F, Midwestern, Wentzville, MO) were used in this study. One of those had traditional handle (TH) and the other had a AV handle (S83F, F&H Mine Supply Inc., Osburn, ID).

The drill handles used for this study can be viewed in Figure 1. In this study, a thin rubber glove was worn and classified as no glove (NG). The AV glove was an Ergodyne ProFlex® 9015F (x) ANSI/ISO-Certified Anti-Vibration Gloves + DIR Protection gloves (St. Paul, MN, USA) and all participants wore a large glove. The TH with NG was used as the control exposure. The summary of the four jackleg drill handles and AV glove combinations, as well as, their associated grip diameters, can be viewed in Table 1.

A palmar triaxial accelerometer (Svantek Model 106A Human Vibration Meter & Analyser, Warsaw, Poland) was used to measure vibration exposure. The accelerometer was calibrated both before and after each measurement, as per manufacturer instructions, using a vibration calibrator (Svantek Model 111).

Frequency weighting was applied to the HAV measurements in accordance with ISO Standard 5349-1 to quantify all frequencies in the band spectrum associated with hand injury

[2]. Surfacelectromyograhpy (sEMG) activity was assessed using Delsys Trigno Wireless mini sEMG Sensors (Natick, MA, USA). A Camry Digital Hand Dynamometer (South El Monte, CA, USA) aided in the assessment of Max Voluntary Contraction (MVC).

Measurement

To assess vibration, a palmar triaxial accelerometer was positioned and attached, with the manufacturer's provided hand strap, and secured with electrical tape in the participant's palm. The accelerometer was located at the interface between the drill handle and the hand during drill operation. Participants were instructed to operate the drill as they normally would. Grip muscle exertion was measured using sEMG, the recording of the electrical activity of muscle tissue with the use of electrodes attached to the skin and transmitted to a visual display. Forearm muscle exertion can be indirectly assessed using sEMG [10]. Three forearm flexor/extensor muscles were analyzed for this study. It has been demonstrated that three randomly chosen forearm muscles have the same validity when predicting grip strength in sEMG modeling as six forearm muscles [10]. Surface EMG electrodes were placed over superficial right forearm muscles, the extensor carpi ularnaris (ECU), extensor digitorum (ED) and flexor carpi radialis (FCR). Muscle exertion in all three of these muscles have been highly correlated with grip force [10]. Placement of electrode was determined by palpation of the participant's forearm muscle belly. Location of muscle bellies was determined by first locating the origin and insertion of the muscle and then having the participant exhibit a range of motion that increased muscle flexion according to procedures described by The Soma Institute of Massage Therapy [11]. Per manufacturers guidelines, electrodes were placed parallel to muscle fiber direction. Skin was prepped with an alcohol pad to remove excess oil and forearm contact sites were shaved if excess hair on participants prohibited electrode contact. Electrodes were secured to contact sites with the manufacturer provided adhesive stickers. Due to the high vibration rate of the drill, electrodes were further secured with the use of a compression sleeve, donned superficially to the electrodes, over the attached electrodes. The sleeve was covered in plastic to prevent moisture from saturing the sleeve and reaching the electrodes. A drill operator wearing the sEMG electrodes, vibration meter and covered compression sleeve can be seen in Figure 2.

In a seated position, holding the wrist in an anatomically neutral grip and squeezing a grip dynamometer as hard as possible, an isotonic contraction of the forearm muscles was captured with the sEMG equipment and recorded as the participant's MVC. The participants were given three seconds to reach maximum contraction, three seconds to release the contraction, and three seconds of rest. Three repetitions of exertion, release and rest of MVC was considered one MVC measurement. Three measurements were taken for each participant with a 30 second break between measurements. The largest contractional magnitude was used as the subjects MVC.

Jackleg Drill Task

A sample was defined by the study design as one completed jackleg drill hole, this included both drilling and removing the steel upon completion of the hole. For this study, jackleg drills were used to bore holes, for either structural support or blasting, into the hard rock. Near the jackleg handle are two control switches, one for the rotational speed of the hammer portion of the drill and one for lowering and rising of the hinged pneumatic drill leg. Continuous drilling and leg adjustment occur during drilling until the hole is bored to completion, at which point the rotational speed of the drill was reduced and the drill bit is removed from the hole. Depending on the rock type, drill bits can become stuck if clay is present, often increasing the operator's physical exertion in removing the drill bit. All drill steel bits were homogeneous other than in length, where some were 1219 mm or 1829 mm (4.0 or 6.0 ft) in length depending on the need of the operator.

Sample times ranged between 86 seconds to 715 seconds. While the sEMG equipment was wireless and controlled from a distance, the HAV meter was stored in a fanny pack worn around the waist of the participant throughout the duration of the sample. At times it was difficult to start and stop vibration data collection simultaneously with the sEMG data collection because approaching the participant was disruptive to their work. Since each sample was monitored with two separate types of equipment, one with remote and local start/stop functions, there are minor time interval discrepencies between vibration and sEMG data.

Data Analysis

Hand-arm vibration exposure data was anaylzed using Svan Supervisor software v.1.9.2. (Warsaw, Poland) in order to calculate a maximum allowable daily exposure time, which was computed using:

$$t_{max} = 8\ hours\left(\frac{5\ ms^{-2}}{a_{hv}}\right)^2$$

where t_{max} is maximum allowable exposure time in hours, a_{hv} is the HAV vibration total value acceleration over the measurement period in m/s^2, and 5.0 m/s^2 is the 8-hour TWA TLV [4].

Muscle exertion was analyzed in Delsys Trigio Wireless System Software (Natick, MA, USA). Participant's greatest MVC measurement was used to normalize each sample, allowing for the calculation of percent MVC (%MVC). The mean %MVC for individual samples allowed for comparison across all samples.

Statistical Analysis

The handle and glove cases among all three muscles independently or segmented by individual muscles of each mean %MVC, as well as the HAV acceleration rates by case, were analysis using a Welch's ANOVA. An $\alpha = 0.05$ significance level was employed for all analyses. To identify significant differences between specific groups, a pair-wise comparison was performed using The Games-Howell post-hoc test with a 95% confidence interval (C.I.). Linear regression was used to access the relationship between HAV exposure muscle exertion, described in terms of R^2. Minitab Statistical software version v.19 (State College, PA, USA) was used for statistical analysis.

Results

Effects of Cases

Null hypothesis H_{o1} was that changes in grip diameter would not effect forearm muscle exertion when operating a jackleg drill . A total of 57-drill hole samples were collected. The mean %MVC, standard deviation (SD) and 95% C.I. among all three muscles combined, as well as three individual muscles, classified by grip diameter were generated are provided in Table 2.

When comparing the mean %MVC of the four different grip diameter among all three muscles, H_{o1} was rejected ($F=12.02$, $p < 0.001$). Post hoc testing revealed a significant difference between AV/G and TH/NG ($p < 0.001$), as well as AV/G and TH/G ($p = 0.003$), and AV/G and AV/NG ($p =0.041$). The comparison is shown in a box and whisker plot in Figure 3.

The mean %MVC of the four different grip diameters were further evaluated by specific forerm muscle. All cases had demonstrated at least one significant difference among handle/glove combinations, specifically ECU ($F=8.23$, $p < 0.001$), ED ($F=38.78$, $p < 0.001$) and FCR ($F=17.94$, $p < 0.001$). Post-hoc testing of ECU revealed a significant difference between AV/G and TH/NG ($p < .002$), as well as AV/G and AV/NG ($p < .001$). Post hoc testing of ED revealed a significant difference between AV/NG and TH/NG ($p < .001$), AV/NG and TH/G ($p < 0.001$), as well as AV/G and AV/NG ($p < 0.001$). Post-hoc testing of FCR revealed a significant difference between AV/NG and TH/NG ($p < .001$), AV/NG and TH/G (p-value = 0.000), as well as, AV/G and TH/NG (p-value= 0.002), and AV/G and TH/G (p-value= 0.003). A visual comparison of the %MVC of the four different grip diameters segregated by muscle group is also provided in Figure 3.

HAV Exposure by Glove/Handle Case

Null hypothesis H_{o2} was that there would be no difference in HAV exposure among jackleg drill operators from the use of AV handles and/or AV gloves. Operators underwent a HAV exposure assessment in each of the four handle/glove cases to determine if any combination of handle and glove reduced HAV exposures by a statistically significant margin. Mean HAV exposures for each case, as well as maximum allowable exposure times (t_{max}), can be viewed in Table 3. When comparing the mean vibration of the four cases a significant difference was not observed ($F=0.29$, $p = 0.835$), and thus post hoc testing was not necessary. A comparison of HAV exposures by handle/glove case is provided in Figure 4.

Relationship Between HAV Exposure and Muscle Exertion

When fitted to a linear regression model, mean HAV exposure was a poor predictor of mean %MVC for pair matched drill hole samples (ECU $r^2= 0.03$, ED $r^2= 0.001$ and FCR $r^2= 0.13$). The relationship between HAV exposure and muscle exertion for each muscle evaluated is provided in Figure 5.

Discussion

There is inconsistent guidance found in the literature regarding optimal grip diameter. Previous investigators [12] found that 19.7% of an individual's hand length represented the optimal grip diameter for any given individual. The researchers evaluated comfort and force during handgrip of various handle diameters. Their findings yielded recommendations for three optimal grip sizes as small (3.4-3.7 mm), medium (3.7-3.9 mm) and large (3.9-4.0 mm) [12]. Another study [13] found that 17.9% of an individual's hand length, following a U shape regression, predicts an individual's optimal grip diameter. Regardless, as grip diameter increases above optimal for an individual, so to must muscle exertion to maintain the same level of grip force.

All participants wore a size large glove, which according to the manufacturer, fits a hand length of 23 to 25 cm. The length of the hand was interpreted to be the length from the base of the scaphoid carpel bone to the distal phalange of third metacarpal bone. Under the Kong and Lowe [12] model optimal grip diameter would fall between 3.9 and 4.0 cm and under the Rossi et al. [13] model it would fall between 4.1 and 4.5 cm. Using the range of both studies combined for conservative purposes, optimal grip diameter would be expected to fall between 3.9 and 4.5 cm for all participants in this study. The only grip diameter that would fall within this range would be TH/G, suggesting that TH/NG, AV/NG and TH/NG would result in statistically significant increased muscle exertion relative to TH/G. The TH/G grip diameter did have the lowest mean %MVC for all muscles, however TH/NG, TH/G, and AV/NG showed no significant difference in mean %MVC when compared to the TH/G grip diameter. The TH/G grip diameter did have the lowest mean %MVC for all muscles combined and for the ECU and FCR muscles individually. The largest of the three-grip diameter AV/G did produce a significantly larger mean %MVC for all muscles combined. Looking at the ECU and FCR as individual muscles, there was an increased forearm muscle exertion. The data for ED muscle activity were unusual, with mean AV/NG (second largest grip diameter) being significantly lower than the other cases.

Jackleg drills have a very high acceleration, in comparison to other tools described in the literature including demolition hammers (9.78 m/s^2), leaf blower (0.60 m/s^2), 9-inch angle grinder (6.56 m/s^2) and whacker plate (6.74 m/s^2) to name a few examples [14]. Given the high exposure magnitudes when working with jackleg drills and the documented potential for grip strength reductions following HAV exposure [1, 15], there was a need to evaluate whether the HAV exposure levels themselves were contributing meaningfully to forearm muscle exertion in addition to tool use and grip interface. However, sEMG activity was not significantly associated with vibration acceleration for all muscles combined analyzed, meaning muscle activity increases independent of vibration magnitude among samples and all observed associations were very weak (Figure 5).

The AV gloves and/or the AV handle did reduce HAV exposures among study participants by a statistically significant margin. In terms of how long you can operate a jackleg drill under the TLV, the TH/NG case represented the HAV exposure without any AV controls. The mean HAV exposure in this case resulted in a maximum allowable exposure time of T_{max} of 49 minutes (Table 3). The greatest increase in T_{max} was by the AV handle and AV glove case, increasing the T_{max}, from that of the control, by 8 minutes to 57 minutes allowed until the operator would exceed the ACGIH TLV. Although there was no statistically significant reduction, the lowest mean HAV exposure level was observed when both AV controls were used together.

The present study revealed a potential trade-off between HAV exposure reduction and forearm muscle exertion, but %MVC differences were modest, as were exposure reductions. The most optimistic results, in terms of HAV exposure reduction, was the AV/G case that afforded the operator a mere 8 extra minutes of jack legging per day before reaching the ACGIH TLV. In contrast, however, that reduction in HAV exposure resulted in a statistically significant increase in %MVC across all muscles combined. The second largest contrasting result, TH/G, allowed for two additional minutes of jack legging per day with no significant difference in %MVC across all muscles combined. The AV handle and AV gloves for this sample of jackleg drill operators at this particular test site had very little influence on lowering the HAV exposure, suggesting modest health benefits at best. On the other hand, increased grip diameter did not have a large effect on %MVC grip effort, except the largest of the grip diameters which was the pairing of the AV handle with the AV glove.

In two other studies, AV gloves have been shown to be effective in reducing HAV [7, 16]. A meta-analysis of AV gloves and their effectiveness against HAV has found that AV gloves can marginally reduce HAV of jackleg drill in the palm [17]. It should be noted that while AV gloves may reduce palm vibration, they often amplify vibration in the fingers [16]. Another consideration is that the relationship between AV gloves and forearm muscle exertion may be predicted not by the grip diameter but by the matrix of the AV material in the glove [16]. Ultimately research this far has shown that AV gloves may not offer significant protection from HAV exposure [17].

The use of AV gloves represents an expense for mining companies and the gloves must be replaced regularly due to wear. Wear may increase in underground mine environments because the gloves can be damaged from collaring drill bits and they are routinely exposed to oil and water. This is an important consideration given the limited advantages of the AV gloves used in this study. The lack of significant AV benefits observed in this study suggest that improved glove and tool designs may be needed for jackleg drill operators. Without more substantial HAV exposure reductions, the increased forearm muscle exertion that can occur when using AV handles and gloves may represent increased risk of injury and illness to jackleg drill operators from using these AV controls.

Limitations

This was a pilot study with several limitations. This study recruited a convenience sample of mining engineering students engaged in drilling operations who may not represent the average miner using a jackleg drill. Further, experience was not assessed during recruitment. Generally, increased exertion would be expected among novice operators as compared to more experienced operators. The one subject who had the most experience drilled 2/3 of the AV/G samples and 1/4 of the AV/NG grip diameter samples. The MWS83F jackleg drill weighs 72 lbs (32.66 Kg). The weight and awkwardness of the tool is best managed by those with skilled trade experience who are familiar with the required strength, coordination, and endurance. This study used a single AV glove type, one jackleg drill model with two variations of handles, and a small sample of operators. An uneven distribution of handle and glove cases was collected, which many have affected comparisons. The ISO HAV evaluation standard has specifications on constant feed force, which is the horizontal push from the body during tool operation [18]. Skilled operators are able to let the drill do the work and apply less force to the handle, which effects transmission of vibration from the tool to the user. This study used a single AV glove type, one jackleg drill model with two variations of handles which are not representative of the range of tools and equipment in use. For these reasons, the results of this study should not be generalized to other AV gloves or AV handles or other populations of miners.

Conclusion

This pilot study proved successful in demonstrating a potentially negative tradeoff between modest and insignificant HAV exposure reductions from the use of AV controls among jackleg drill operators, and a statistically significant increases in forearm muscle exertion. Further study is needed to determine what implications such a trade-off may have on drill operators’ musculoskeletal health. Limited hazard control trade-offs exist for the four cases analyzed in this study. The most profound trade-off was the largest of the three-grip diameters, the AV/G case, produced a significant increase in forearm muscle exertion for all muscles combined, and for ECU and FCR individually, when compared to all other cases, despite a small and insignificant decrease in HAV exposure.

More research is needed to determine if the apparent trade-off identified in this study exists among experienced drill operators using AV controls. Additional future research efforts should focus on improving HAV exposure controls for jackleg drill operators with a consideration of any potential increased risk of musculoskeletal disorders.

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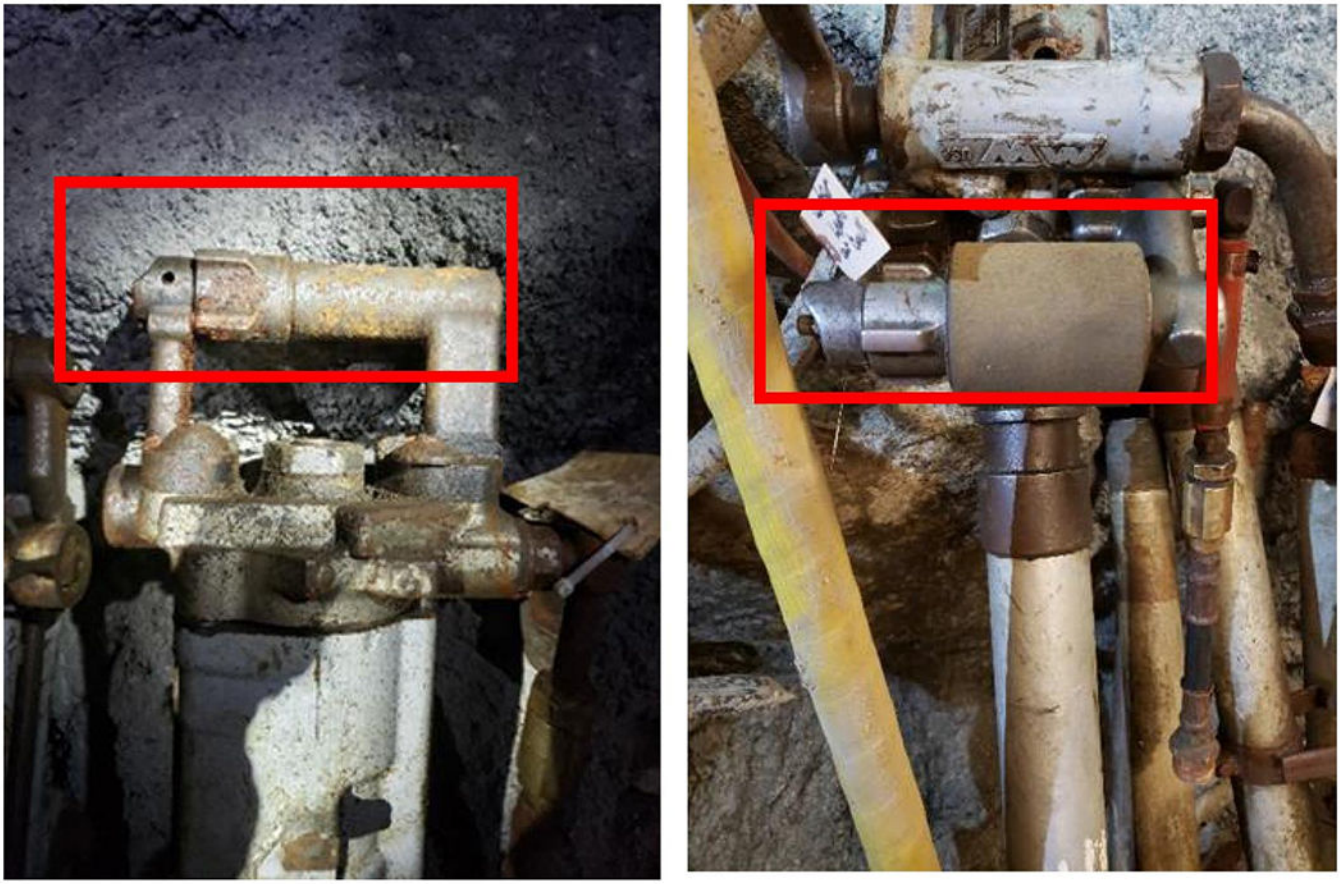

Figure 1:

Traditional Handle (left) and AV Handle (right)

Figure 2:

The EMG sensors positioned on a participant’s forearm (left photo), the HAV accelerometer strapped to a participant’s palm (center) and the infield set up of sEMG sensors and accelerometer, on participant, ready for drilling (right).

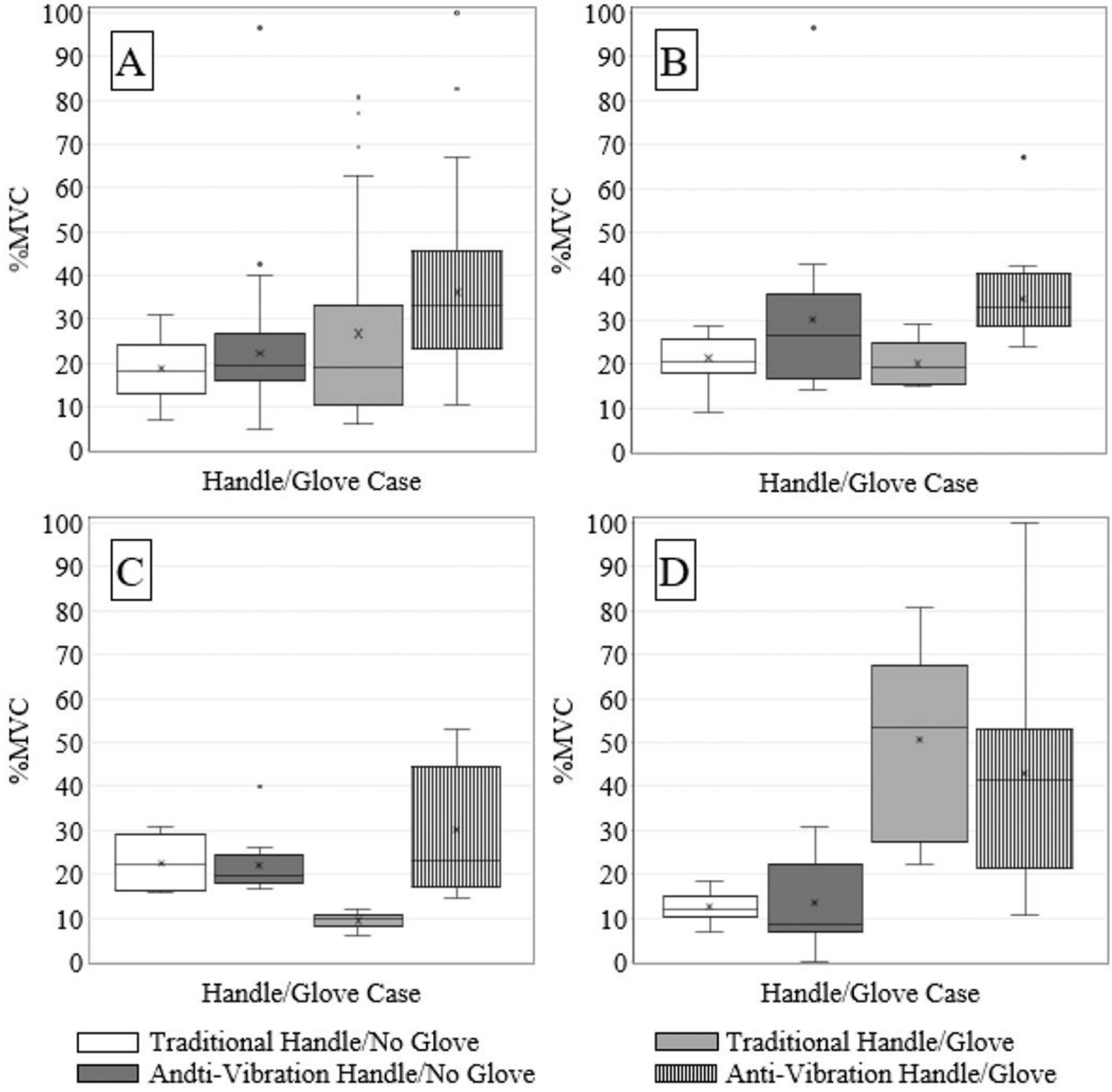

Figure 3:

Box and whisker plot comparison of operator muscle exertion using a jackleg drill as measured using sEMG by handle/glove case, overall and by specific forearm muscle. A) %MVC for each case averaged using the three evaluated forearm muscles, and B) %MVC for the extensor carpi ulnaris muscle, C) the extensor digitorum muscle, and D) the flexor carpi radialis muscle.

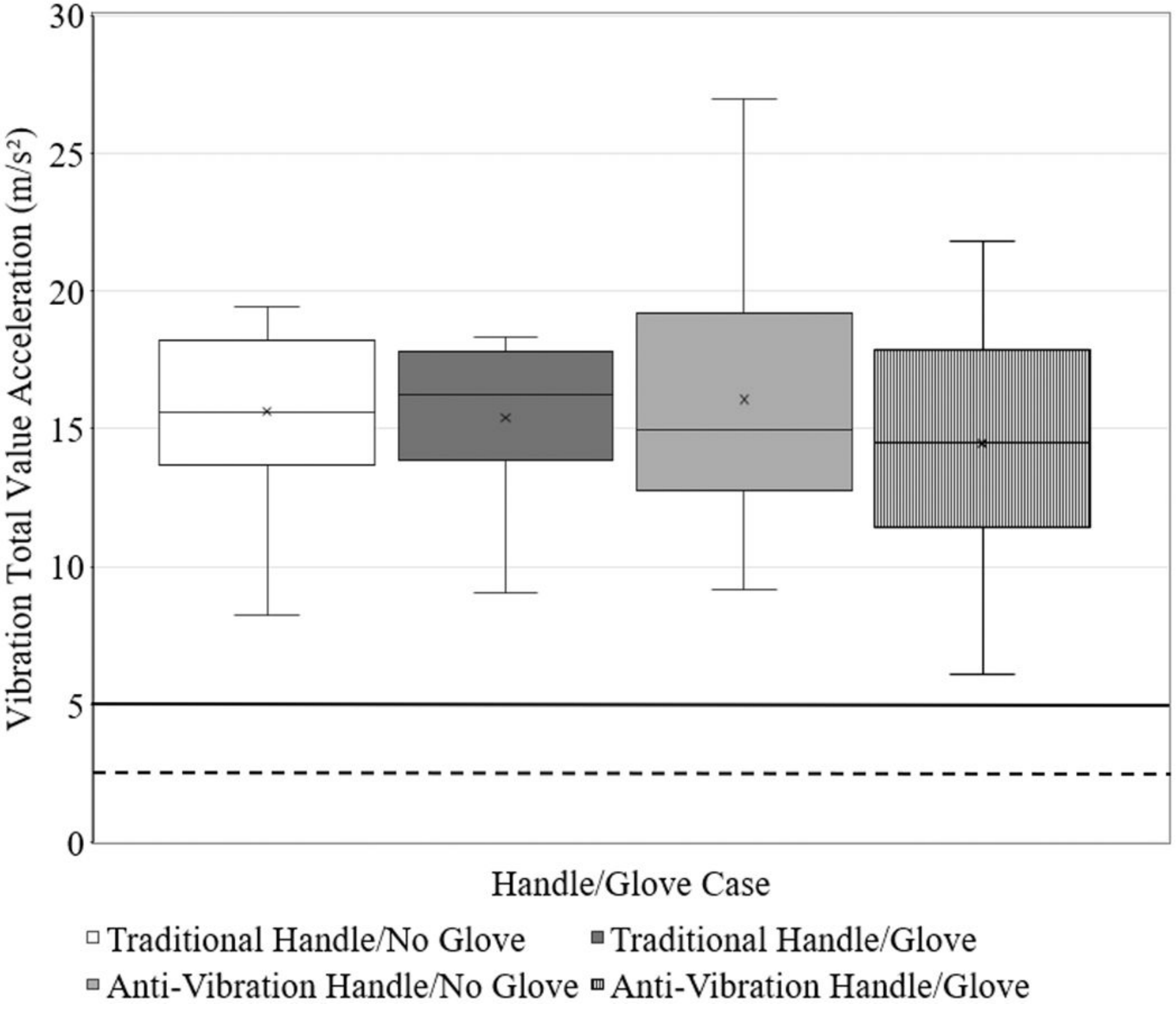

Figure 4:

Box and whisker plot comparison of HAV exposure by handle/glove case. The solid black line indicates the ACGIH TLV for HAV of 5.0 m/s^2 and the dashed line represents the ACGIH AL for HAV of 2.5 m/s^2 [4].

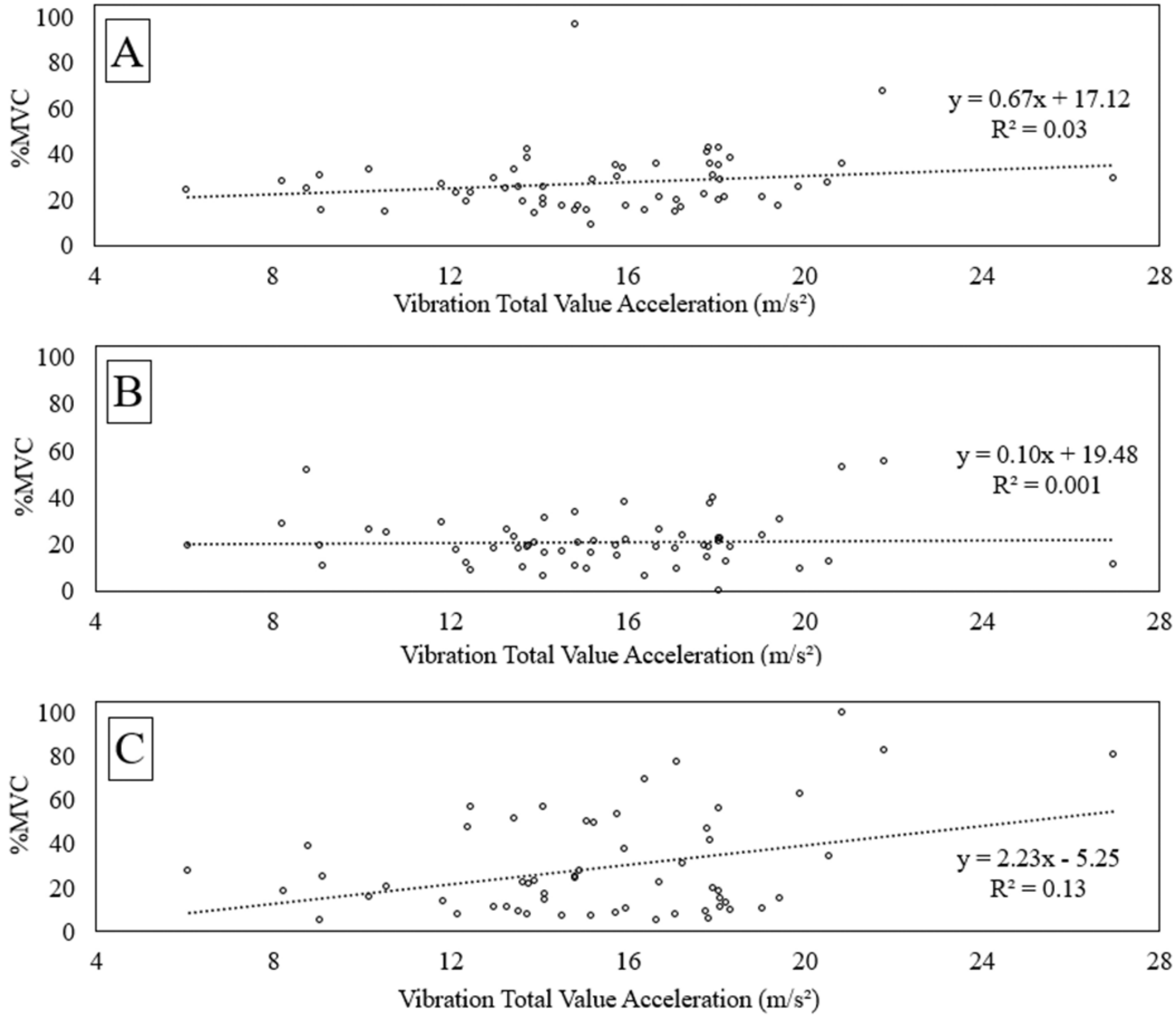

Figure 5:

Scatterplots depicting the relationship between HAV exposure and operator muscle exertion for A) the extensor carpi ulnaris muscle, B) the extensor digitorum muscle, and C) the flexor carpi radialis muscle.

Table 1:

Grip Diameter of Glove and Handle Combinations

Handle and Glove Case	Abbreviation	Grip Diameter (mm)
Traditional handle without anti-vibration glove	TH/NG	34.0
Traditional handle with anti-vibration glove	TH/G	49.9
Anti-vibration handle without anti-vibration glove	AV/NG	60.6
Anti-vibration handle with anti-vibration glove	AV/G	76.6

Table 2.

Muscle Exertion as a %MVC by Jackleg Drill Handle and AV Glove Combination

		Mean % MVC (SD) and [95% Confidence Interval]			
Handle/Glove Case	**N**	**All Muscles**	**ECU**	**ED**	**FCR**
TH/NG	12	18.75 (6.67)	21.37 (5.49)	22.38 (5.97)	12.50 (3.38)
		[16.57, 20.93]	[18.26, 24.47]	[19.00, 25.75]	[10.59, 14.41]
TH/G	18	22.08 (13.98)	30.03 (19.16)	21.87 (6.04)	14.33 (8.68)
		[18.35, 25.81]	[21.18, 38.88]	[19.08, 24.66]	[10.33, 18.34]
AV/NG	12	26.77 (21.24)	20.14 (4.89)	9.56 (2.00)	50.62 (20.41)
		[19.84, 33.71]	[17.37, 22.91]	[8.43, 10.69]	[39.01, 62.16]
AV/G	15	36.13 (18.19)	34.99 (10.6)	29.94 (14.47)	43.05 (24.86)
		[30.75, 41.50]	[29.62, 40.35]	[22.36, 37.52]	[30.47, 55.63]

Table 3:

Mean HAV Vibration Acceleration by Handle/Glove Case and Associated Maximum Allowable Exposure Times

Handle/Glove Case	Vibration Total Value Acceleration Mean (SD) m/s^2	Maximum Allowable Exposure Time Minutes
TH/NG	15.6 (3.2)	49
TH/G	15.4 (2.7)	51
AV/NG	16.0 (4.7)	46
AV/G	14.7 (4.4)	57