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Grip Characterization of Protective Gloves

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GRIP CHARACTERIZATION OF PROTECTIVE GLOVES

by

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ABSTRACT

GRIP CHARACTERIZATION OF PROTECTIVE GLOVES

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In 2014, ASTM International (ASTM), one of the world's largest international standards developing organizations, published a new test method on glove grip performance. This method was adopted by the National Fire Protection Association (NFPA) in some of their specification standards. The method utilized hand torque instead of the pull method previously used by the NFPA to determine the Percent Bare Hand Control Value (%BHCV). The %BHCV, compares torque results of a gloved hand versus a bare hand. In developing this new test method, only four males and one female participated; therefore, it is unclear if statistical significance was attained. In addition, there was no indication that consideration was given to age, hand size, or sex. So, to rectify this, the overall objective of this dissertation was to fully validate and enhance the ASTM test method.

Our first study used 33 females and 35 males to determine if five iterations of the torque meter was needed to get accurate results. It also evaluated if the 1.625 in. diameter acrylic rod size chosen by the original developers was acceptable based on a person's hand size, measured by both girth and by Digit3 Link Length. Test participants were asked to torque four differing sized rods five times with their bare, self-declared dominant hand. Analysis of results by gender, hand size, Digit3 link length determined that the 1.625 in. diameter rod size, as required by the test

method, did not have significantly higher torque results regardless of hand size or gender. However, after further analysis, the 1.625 in. rod size, gave the most consistent results between males and females. In addition, for bare hands, the number of iterations can be reduced to four rather than the current five iterations.

Our second study utilized optimizations realized in the first study to determine the grip characterization of two disparate glove types. Study participants, 43 females and 42 males, were asked to torque a 1.625 in. acrylic rod five times with their bare, self-declared dominant hand, then again with a leather glove, and again with a polymer dipped glove. The sequence of these iterations was randomized. We found age, sex, and hand size were not factors in obtaining valid %BHCV, defined as the percentage of mean maximum torque of gloved hand divided by the mean maximum torque of bare hands. We also found that the 4.5 Newton meters (N m) minimum torque requirement of the test method was unnecessary and would disproportionately impact females. In addition, we also found that using four test subjects would return more consistent results without a considerable increase in cost.

The final study examined the relationship between grip strength using a dynamometer and glove grip characterization using Percent Bare Hand Control Value. Our results (n=32) showed that a glove with higher %BHCV reduced the grip strength needed to achieve maximum torque. This is important in that if greater grip strength is needed to do work while wearing a glove (such as climbing a ladder or getting on or off equipment), a glove with better %BHCV should be considered. We believe the results of this study verify that grip strength measurements are not needed as part of the ASTM test method.

This research project validated parts of the ASTM test method for glove grip characterization: even though torque performance may differ between individuals, the percent torque difference between gloved and bare hand by the same person was found to be significantly similar regardless of glove size, sex, or age. In addition, this project uncovered changes that should be considered for the next version of the test method: removal of the 4.5 N m minimum torque requirement and using four test subjects instead of three. Lastly, now that this test method is fully validated, we believe it can be used to determine grip characteristics of gloves when wet with water and when wet with oil. The endpoint would be to develop a grip performance rating system to assist employers in selecting the most appropriate glove for their work environment and job needs.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
%BHCV	Percent Bare Hand Control Value
°C	degrees Celsius
°F	degrees Fahrenheit
ANSI	American National Standards Institute
ASSP	American Society of Safety Professionals
ASTM	ASTM International
BLS	Bureau of Labor Statistics
CINAHL	Cumulative Index to Nursing and Allied Health Literature
cm	centimeters
COF	coefficient of friction
CV	Coefficient of Variation
DTT_b	barehanded control value
DTT_g	average twisting force with glove
EN	European Standards
HPT	Proprietary synthetic dip used on Ninja Ice gloves by MCR
in.	inches
ISEA	International Safety Equipment Association
ISO	International Organization for Standardization
MET	Maximum Endurance Time
min	minute
mm	millimeters
MVC	Maximum Voluntary Contraction
N m	Newton meters
NASA	National Aeronautical and Space Administration
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety & Health Administration
PPE	Personal Protective Equipment

T_B	average maximum torque applied with bare hand
TFG	Total Force Generation
T_G	average maximum torque applied with gloved hand
T_{MVC}	Time needed to reach Maximum Voluntary Contraction
WPC_b	bare-handed weight lift capability
WPC_g	weight-pulling capacity with gloves
µin	microinches
µm	micrometers

CHAPTER 1: INTRODUCTION

Personal Protective Equipment (PPE) is vital for worker safety. Protective gloves are a major component of PPE and are ubiquitous throughout industry. Employers are required to ensure that the PPE they select will protect workers from the hazards identified on the job (Occupational Safety & Health Administration, 2016). There are many attributes of protective gloves that end users need to consider. As shown in Figure 1.1, many of the attributes are

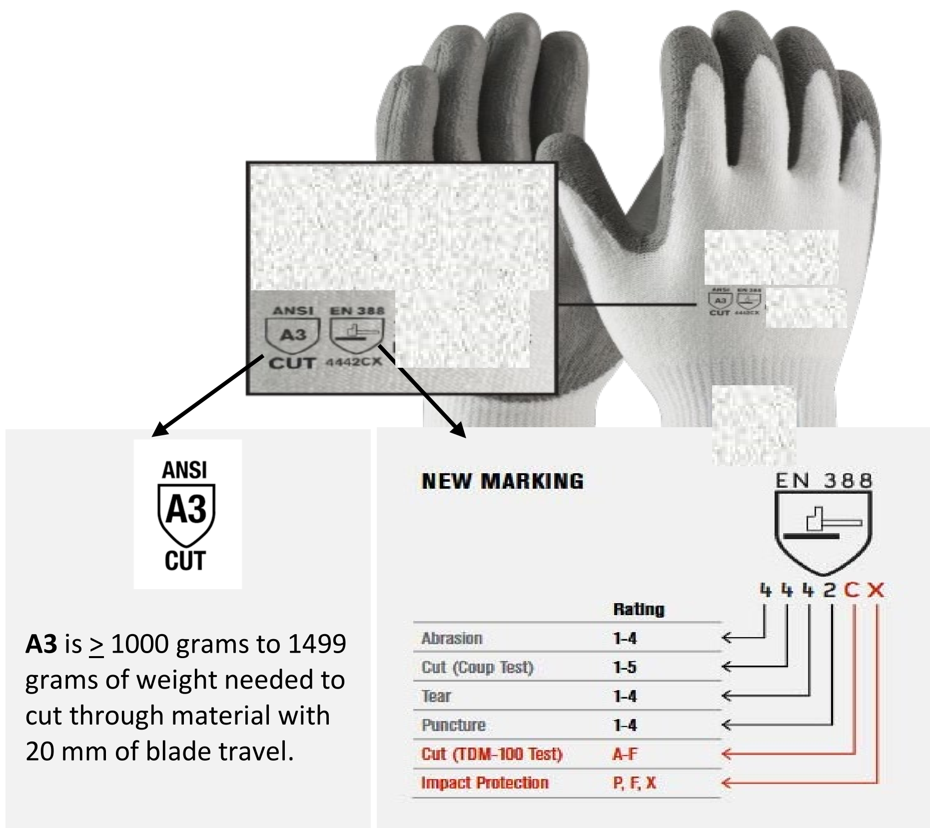


Figure 1.1: Example of glove markings. Source: ANSI / ISEA 105-2016 and EN388-16

readily identified on the glove itself. Other attributes are in the product literature. But one attribute is currently not found on the glove or in most literature – that of glove grip characterization. The term "Grip Characterization" refers to how well or poorly a glove creates friction against a solid object. It is usually measured as a comparison of the friction of a gloved hand to a solid object to that of the friction of a bare hand to the same object. It is not difficult to understand why glove grip is important in industry. Gloves with good gripping ability can improve worker safety, improve workplace efficiency, and perhaps reduce fatigue. Therefore, we believe it is important that employers have a way to easily identify the grip characteristics of protective gloves.

This dissertation will discuss the current test methods to characterize glove grip and then complete our overall objective of validating and enhancing the method currently published by ASTM International (ASTM). The current method requires three people, with a torquing ability of 4.5 N m to 9.5 N m, to torque a 1.625 in. diameter acrylic rod mounted vertically on a torque meter. The test participants torque the rod five times with their bare hand, resting one minute between each attempt. Then, they rest for five minutes and repeat the process with a gloved hand. The average amount of torque achieved with the gloved hand is compared to the average amount of torque achieved with the bare hand. This is called Percent Bare Hand Control Value (%BHCV). This comparison is helpful to determine if a glove enhances or decreases a person's ability to grasp a solid object (ASTM International, 2022b).

1.1 Research questions

The research questions that we aimed to answer by conducting this research project were:

1. *Does the diameter size of the acrylic rods produce differing average maximum torque values based on hand size?* The question of differing rod size versus a person's hand size was not addressed in the ASTM F2961 method or in the background documentation that led to the standard.

2. *How many iterations of torquing the acrylic rod is adequate to obtain consistent, average maximum torque results?* Current ASTM F2961-22 Test Method dictates five iterations. This could lead to muscle fatigue if multiple glove styles are tested in one day, or if the number of iterations can be reduced, more gloves styles can be tested in one day, creating greater throughput for the testing laboratory.
3. *How many iterations are needed for most test participants to achieve the highest torque?* Although not part of the test method, this information would provide insight into the number of torquing iterations required to get consistent results and when muscle fatigue may become an issue.
4. *Are three test participants adequate to give consistent %BHCV results*? Current method requires only three people to conduct the test.
5. *How do the torquing abilities of males and females differ?* We already know that males are physically stronger than females; how does this convert to torquing ability? If there is a significant difference, it may impact the %BHCV achieved by each sex and, therefore, the test method might need some sort of normalizing value applied.
6. *How does torquing ability relate to age?* Through previous research, we know that a person's grip strength varies over time, peaking in mid-career age. Again, how does this impact torquing ability and %BHCV, and does the test method need a normalizing value to account for age?
7. *Does %BHCV differ significantly between males and females?* If this is the case, we may have to develop a normalization factor to account for the difference.
8. *Does %BHCV differ significantly based on age?* Again, if there are significant differences, a normalization factor may need to be developed to account for age.

9. *Is it necessary to require test subjects to torque a minimum of 4.5 ?* This requirement may impact females greater than males based on research that shows that females are not as strong as males. If we can show it is not a factor, then laboratories may find it easier to recruit test participants.
10. *Must a person grip harder in certain types of gloves to achieve maximum torque?*
11. *Does a glove with high %BHCV require greater or lesser grip strength while torquing the acrylic rod?*

1.2 Approach to answer research questions

This research project and dissertation used a three-step process to answer the research questions.

Step One – Method Optimization: Questions 1, 2, 3, 5, and 6, are investigated in Step One. Question number one is answered so that Step Two can be accomplished. The answer to that question is answered based on hand size measured by girth and by Digit3 Link Length. In addition, we determined if rod size made a difference based on test participant sex. The results showed which rod size is optimal to give consistent, mean maximum torque results across the test population.

Step Two – Grip Characterization: Questions 2, 3, 5, and 6 are confirmed in Step Two. In addition, questions 4, 7, 8, and 9 are answered in Step Two. Using the information from Step One, we determined the number of iterations and rod size. We determined if %BHCV would be significantly different by sex, by age, or by differences in torquing ability. We also determined the number of test subjects and number of torquing iterations needed to achieve the most consistent results. Lastly, we determined if hand size was a significant factor in how much the test subjects could torque and if it impacted the Percent Bare Hand Control Value.

Step Three – Grip Strength vs Grip Characterization: Questions 4, 7, 8, and 9 are confirmed in Step Three. Questions 10 and 11 are answered in Step Three. Many times, the hand will move inside the glove when performing torquing or other tasks of this nature. If a glove has great grip performance, but it causes a person to grip stronger, it may not be beneficial. Therefore, in this step, we use a Tekscan® Tactile Grip Force and Pressure Sensing system, to determine if the actual grip force exerted while torquing the acrylic rod differs by glove type. Grip strength is defined as a person's hand strength, in pounds, measured with a hand dynamometer.

1.3 Organization of dissertation

This dissertation is arranged to follow the flow of the 3-step process.

Chapter 1 introduces the reason for this research project and describes how this dissertation is organized.

Chapter 2 presents a synthesis of current knowledge on the subject and identifies research gaps that are more background on the current test methods and describes those methods in enough detail to understand the gaps this research project is attempting to close. It also provides a literature review and what contributing information must be considered in validating and enhancing the current ASTM test method.

Each of the next three chapters explain the three-step process we used to validate and enhance the current test method.

Chapter 3 describes the Method Optimization step.

Chapter 4 describes the Grip Characterization step.

Chapter 5 describes the Grip Strength versus Grip Characterization step.

Chapter 6 recaps the conclusions that were discussed in each step of the research project. It also answers the research questions posed in the first chapter, states the strengths and limitations of this research, and makes suggestions for improvement of ASTM F2961-22 test method. In addition, we suggest follow-on research to make glove grip characterization even better.

CHAPTER 2: LITERATURE REVIEW

2.1 Protective Glove Requirements and Standards

The purpose of protective gloves is to enhance productivity while reducing worker injury. According to the United States Bureau of Labor Statistics (BLS), during the 5-year period of 2016 through 2020, the number of hand injuries were 42.3% of all upper extremity injuries. Hand injuries accounted for 12.4% of all injuries during that same time frame (Bureau of Labor Statistics, 2016, 2017, 2018, 2019, 2020). What is not known is how many of these injuries had a contributing or causal relationship with the use, or lack thereof, of protective gloves. In addition, there is no indication or data regarding other injuries that may have had a contributing or causal relationship to protective glove use. For example, there is no information that a glove with poor grip contributed to someone falling while trying to grasp a handrail or ladder rung.

According to McKinsey & Company, a leading global management consulting firm, sales of PPE in the United States was estimated to be $13.5 billion in 2019 and is expected to increase to over $24 billion by 2024. The sales of protective gloves made up approximately 30% of that total (Jaju *et al.*, 2021). This section will cover the requirements and standards associated with protective equipment, and specifically, protective gloves.

2.1.1 Occupational Safety & Health Administration (OSHA)

The U.S. Occupational Safety and Health Administration (OSHA) requires all employers to provide to their employees a “place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees ("Occupational Safety & Health Act of 1970, 29 USC §651 *et seq.*," 1970).” In addition, OSHA requires that employers assess the workplace to determine if hazards are present, or are likely to be present, which necessitate the use of personal protective equipment. If such hazards are present, or likely to be present, the employer must select, and have each affected employee use, the types of PPE that will protect the affected employee from the hazards identified. The employer must also communicate selection decisions to each affected employee; and select PPE that properly fits each affected employee (Occupational Safety & Health Administration, 2016).

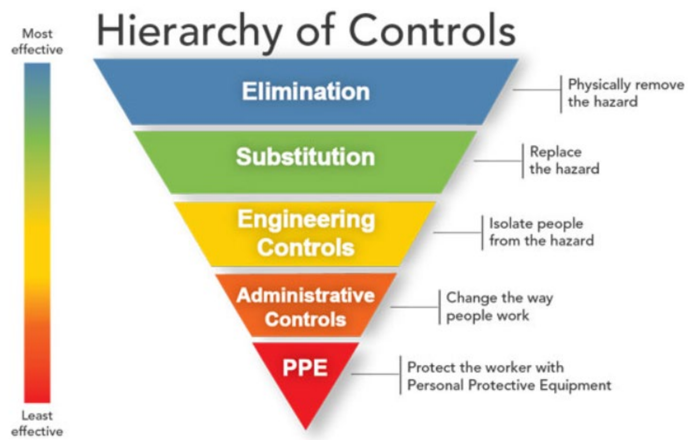


Figure 2.1: Hierarchy of Controls. Source: NIOSH

Protecting workers on the job is done by controlling exposures to hazards in the workplace. The National Institute for Occupational Safety and Health (NIOSH) uses a 5-tier Hierarchy of Controls to determine which actions will best control exposures. After examining all other options to mitigate a safety hazard as explained by hierarchy, PPE is sometimes the only viable control option (National Institute for Occupational Safety and Health, 2015).

Personal Protective Equipment, although the least effective control measure as shown in Figure 2.1, is still vital for worker safety. For example, hard hats are predominantly worn on construction sites to help prevent injuries from overhead impact exposures that cannot be mitigated due to the dynamic nature of these sites. Likewise, automation cannot fully replace the manual cutting in the meatpacking industry; therefore, cut-resistant gloves such as Kevlar® or stainless-steel mesh are used to prevent serious cuts to employees.

With the expanse of jobs requiring the use of hands, from simple hand-stitching of clothing to glaziers making and installing windows to welders to electricians to arctic workers to meatcutters, there needs to be a variety of protective gloves. For employers, who must select the correct PPE for the exposure, this variety can be confusing and even difficult. For example, someone who cuts meat may need a cut-resistant glove but because of the work conditions, must also provide warmth and some amount of dexterity. Likewise, for a welder, a glove will need to be flame resistant and provide protection from extreme heat, protect from molten metal and sparks, yet still provide a modicum of dexterity so the welder can grasp the electrode holder or wire nozzle. However, OSHA does not specify what gloves to wear, only that the employer must evaluate and choose the right PPE for the task. Employers rely on their PPE vendors to recommend the correct equipment. Both the vendor and the employer must be aware of applicable consensus standards in that selection process because OSHA can and does cite employers for selecting the wrong equipment that does not adequately protect the worker.

2.1.2 Consensus Standards

Consensus standards are recommendations or best practices created by a group of experts in a specific field. The standards provide guidance and typically have no regulatory impact unless adopted by a regulatory body. In the case of OSHA, they may not officially adopt a consensus standard but use these standards when citing the General Duty Clause as explained earlier. In the category of protective gloves alone, there are 36 consensus standards, test methods, and requirements of the United States and of European countries (Burns, 2017).

With all these published consensus standards, test methods, and regulations, it is challenging for employers and vendors to comprehend, process, and comply with this massive amount of information. So, in 2017, using the 36 consensus standards and incorporating 40 individual attributes of protective gloves, we developed a computer application to help end users and glove salespersons select the right protective glove based on the hazards of a particular task (Burns, 2017). Attributes ranged from ensuring innocuousness of the materials used in the construction of the glove (Deutsches Institut für Normung e. V., 2010b) to electrical insulation (ASTM International, 2014a) to vibration reduction (ANSI/ASA/ISO, 2014; ANSI/ISEA, 2016). What is unique about this application is that it considered the interaction of one test method or standard against others. For example, for a glove to be considered resistant to contact cold it must also be waterproof, have a defined level of abrasion resistance, and a defined level of tear resistance (British Standards Institution, 2006). This application also incorporated grip characteristics of protective gloves as an attribute using a relatively new (2015) ASTM International test method as the source document for the specification (Ali & Burns, 2017).

2.2 Current Glove Grip Test Methods

2.2.1 National Fire Protection Association (NFPA)

The National Fire Protection Association (NFPA) is one of the oldest organizations devoted to eliminating death, injury, and property loss due to fires. They have more than 300 consensus codes and standards, and participate in research, training, education, outreach, and advocacy (National Fire Protection Association, 2022). Most municipal and state fire codes got their start with NFPA and were simply adopted by the jurisdictions having authority.

As early as 1973, the NFPA has considered glove grip in its standards. The first standard promulgated, although temporary, simply directed local fire departments to consider grip as part of its selection process for firefighting gloves. This temporary standard, NFPA 19A-T, was considered a specification standard to assist fire departments with procuring acceptable gear and had no specific test method delineated for glove grip (National Fire Protection Association, 1973). In November 1975, NFPA 19A was withdrawn and became NFPA 1971, *Standard on Protective Ensemble for Structural Fire Fighting*. The standard was updated in 1981, 1986, and 1991 to make it more user friendly but there were no changes regarding grip characterization.

In 1983, NFPA also published NFPA 1973, *Gloves for Structural Fire Fighters*. This first edition did not have a test method for grip characterization but incorporated a simple test in its 1988 and 1993 editions. That test method required glove samples to be laundered five times and then subjected to hand flexing once the test subject donned them. Five test subjects used bare hands, wore dry gloves, and wore wet gloves to pull on a 3/8 in. diameter pre-stretched rope with a measurement device attached. A dry rope and a wet rope were used in the test. The specification was that test subjects wearing gloves must be able to lift at least 80% of the weight they could lift with their bare hands, whether dry or wet (National Fire Protection Association, 1988, 1993).

In 1997, NFPA 1973 was incorporated into NFPA 1971 and discontinued. The test method became more detailed but essentially remained the same; that is, pulling on a dry rope and wet rope with bare hands, dry gloves, and wet gloves. However, only three test subjects were now required and the measurement result of "Percent of Bare-handed Control" was introduced (National Fire Protection Association, 1997), which was calculated per Equation 2.1:

$$\frac{WPC_g}{WPC_b} \text{ x } 100 = \text{ \% bare-handed control}$$

Where:

WPC_g = weight-pulling capacity with gloves

WPC_b = bare-handed weight lift capability

Equation 2.1: Percent of bare-handed control equation, NFPA 1971-1997

In the 2000 edition, the standard modified the metric diameter of the rope from 9.5 mm to 10 mm but kept the imperial 3/8 in. measurement the same. It also changed the specification to 90% instead of 80% bare-handed control (National Fire Protection Association, 2000). In the 2007 edition, NFPA combined firefighting gear for structural and proximity fires into NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*. This standard used the same test method as before but used a different specification for gloves in each situation – 80% for proximity, 90% for structural firefighting.

The 2013 edition completely rewrote the grip test and incorporated a torque test as well. The grip test now consisted of a downward pull of a 3.2 cm (1 ¼ in.) diameter fiberglass pole attached to a calibrated force measuring device. During a five second iteration of pulling, the minimum pull force is compared to the peak pull. Any drop in force of greater than 30%

in any 0.2-second interval constitutes a failing performance (National Fire Protection Association, 2013). The torque test method was based on the 2011 research conducted by Ross *et al.* and was presented at the Performance of Protective Clothing and Equipment: Emerging Issues and Technologies Symposium hosted by ASTM in Anaheim, California (Ross *et al.*, 2011). The calculation was similar to the previous NFPA rope test and was calculated per Equation 2.2:

$$\frac{DTT_g}{DTT_b} \times 100 = \text{ \% bare-handed control}$$

Where:

DTT_g = average twisting force with glove

DTT_b = barehanded control value

Equation 2.2: Percent of torque bare-handed control equation, NFPA 1971-2013

A minimum of 80% was required for firefighting gloves. This research was adopted by ASTM and is discussed in more detail in the next section. The 2018 edition (latest edition), NFPA 1971 references the ASTM test method instead of making their own requirements. Now, these test methods are referenced in several other NFPA standards for rescue and firefighting activities.

2.2.2 ASTM International (ASTM)

ASTM International is one of the world's largest international standards developing organizations with over 12,000 active standards. They believe the adoption of their standards improve product quality, enhance health and safety, strengthen market access and trade, and build consumer confidence (ASTM International, 2022a). The range of products impacted by ASTM standards is diverse and includes metal alloys, concrete and aggregates, packaging, adhesives, and personal protective equipment, just to name a few.

In 2014, ASTM published their first test method to characterize glove grip performance; ASTM F2961-14 *Standard Test Method for Characterizing Gripping Performance of Gloves using a Torque Meter*. This method used the research conducted at North Carolina State University and published in the ASTM Proceedings of their 2011 Anaheim Symposia (Ross *et al.*, 2011). It was the same research that was adopted by the NFPA 1971-2013 in their torque test. The study described the NFPA's rope lift and fiberglass pole pull methods for measuring grip performance of structural firefighting gloves and introduced the torque method (ASTM International, 2014b). As shown in Equation 2.3, the test method designates glove grip performance by calculating the percentage of bare-handed control value similar to the NFPA method.

$$\frac{T_G}{T_B} \times 100 = \%BHCV$$

where:

%BHCV = percentage of bare-handed control value,

T_G = average maximum torque applied with gloved hand, and

T_B = average maximum torque applied with bare hand.

Equation 2.3: Percent of torque bare-handed control equation, ASTM F2961

Values higher than 100% BHCV indicate that gloves tested enhances the wearer's ability to torque the acrylic rod while values lower than 100% decreases the wearer's ability (ASTM International, 2022b). The study demonstrated that a torque-type test method for evaluating the grip performance of structural firefighter gloves had less subject-to-subject variability and greater range of measured grip ratings than any test method developed by the NFPA at that time (Ross *et al.*, 2011).

The method was updated in 2015, which changed the description of the test method to make it clear that a person must grip and twist an object rather than just grip it (ASTM International, 2015). Then, a scheduled review was conducted in 2022 and the standard republished. The 2022 update allowed the use of different torque meters (ASTM International, 2022b). However, the main process has not changed since inception of the standard and is summarized below.

<u>Apparatus – Torque Meter</u>

- *Capable of measuring at least to 10.0 ± 0.5 N m.*
- *Able to be fastened in place or heavy enough to be immobile during testing.*
- *Able to measure torque in either a clockwise (for left-handed people) or counterclockwise (for right-handed people) direction.*
- *Able to be fitted with an adjustable rod holder fixed to the upper surface of the meter.*

<u>Attachment – Rod Holder</u>

- *Adjustable rod holder attached to the torque meter capable of securing a 1.625 in. smooth acrylic cylindrical rod.*
- *Rod holder has four 10 mm diameter metal pins, covered with a rubber material that is between 2.5 and 3.0 mm thick, protruding upwards 30 mm from the surface of the holder.*

Transparent Cast Acrylic Rod

- *Measures 600 mm (24 in.) in length and has a diameter of 41.5 mm (1.625 in.).*
- *Has a surface roughness value of 0.10 ± 0.05 µm (4 ± 2 µin.) and is free of visual scratches and blemishes.*
- *Has four grooves cut into the bottom of the rod matching the size of the metal pins with rubber covering.*

Test Specimens and Conditioning

- *Use a minimum of three untreated, unworn glove specimens for testing each model or type of glove; that is, specimens must be in a new, as-distributed condition.*
- *Right-handed persons use right-handed glove specimens; Left-handed persons use left-handed glove specimens. Participants self-declare which is their dominant hand.*
- *Each glove specimen is used by one person and then, removed from testing.*
- *All glove specimens will be conditioned at a temperature of 21 ± 3 °C (70 ± 5 °F) and a relative humidity of 65 ± 5 %, until equilibrium is reached or for at least 24 hours.*

Procedure

- *Use a minimum of three test subjects with similar hand sizes and who can obtain a bare hand average maximum torque applied value T_B greater than 4.5 N m but less than 1.0 N m below the maximum measurement capacity of the torque meter.*
- *Fit the self-declared, dominant hand of each test subject with a new, appropriately sized glove, as per manufacturer's recommendations.*
- *Conduct a bare hand torque measurement using the person's dominant hand at the beginning of a testing cycle.*

- *Set the torque meter appropriately based on self-declared, dominant hand.*
- *Test subjects should stand with feet parallel, shoulder-width, and facing the testing apparatus. Then, they should grab the acrylic rod with the elbow bent at a right angle and the upper arm against the side of the body. Adjust the rod if necessary.*
- *The test subject should place their non-dominant arm at the body's side during testing.*
- *Firmly grasping rod, the test subject makes five successive attempts to twist the rod. Each torque attempt (i.e., repetition) and the one-minute rest period counts as an iteration.*
- *Each repetition must last no longer than five seconds. Then, the test subject should rest for one minute and attempt another repetition until all five iterations are completed.*
- *The test subject's rotation during the repetition should be in the wrist rather than in the shoulder.*
- *Record the maximum torque applied after each repetition. Average the maximum torques achieved in the five repetitions and identify it as* T_B.
- *Allow the test subject to rest for a minimum of five minutes after the last torque.*
- *Have test subject don the glove specimen on the same hand and repeat the testing protocol.*
- *Record the maximum torque applied after each attempt of the gloved hand. Average the maximum torques achieved in the five attempts and identify it as* T_G.
- *Compare the average maximum torque with a gloved hand with the bare-handed average maximum torque for each test subject.*

Considerations

- *Test should be conducted without the being able to observe the reading from the torque meter or learn of the applied torque during any attempt to twist the rod. They also should not be encouraged during the torquing repetition.*
- *No more than four testing cycles on the same day are allowed for a test subject. This is to reduce hand fatigue. A testing cycle consists of the five bare hand iterations, followed by a mandatory 5 min rest, followed by the five gloved hand iterations.*
- *Test subjects must wait 15 min before conducting another test cycle*

This research project is to validate and enhance the ASTM F2961-22 test method. This method was chosen because ASTM is a leading, global standards developing organization, the method is now referenced in several NFPA standards, and there were some areas in the previous study that we believed needed review.

2.3 Current state of knowledge on glove and hand Interactions

To conduct our literature review on glove grip characterization, we started with the ASTM Standard itself. This included reviewing the work product of the ASTM F23.60 Subcommittee that was used to promulgate the test method, and the proceedings of the F23 Symposium where the original research was presented (ASTM International, 2011, 2014c). The proceedings gave insight into other grip characterization standards currently in use by the NFPA in specifying fire-fighter turn-out gear as well as research by a Canadian team that was also investigating different approaches for measuring glove grip.

Referred to as glove adherence, this Canadian team's research was also published by ASTM in the same proceedings. However, they had previously presented their findings at the 2008 Human Factors and Ergonomics Society Annual Meeting in New York City. Their research, on *Mechanical and Biomechanical Approaches for Measuring Protective Glove Adherence* studied the use of a TDM-100, a piece of specialized testing equipment used to measure cut resistance, to measure the coefficient of friction (COF) of glove textiles against a stainless-steel probe. However, their research compared human perception of grip performance against the mechanical results to see if there was validity to the mechanical test method. Their conclusion was that the test method was capable of measuring static as well as dynamic COFs for a large variety of gloves. They surmised that the method was simple and inexpensive; and it also provided additional uses for the TDM-100 apparatus, a system that is part of the ISO and ASTM standards on cut resistance of protective materials and was already used by several glove manufacturers. In their opinion, the proposed mechanical method was a good candidate to become a standard method for classifying the adherence level of gloves for the ASTM F23 committee on Personal Protective Clothing and Equipment. They planned future work focusing on validating the test method under various experimental conditions such as using a different solid material or with contaminants (Gauvin *et al.*, 2008). However, at the time of this writing, no future research has been published, most likely because the ASTM F23 committee approved a different test method.

We were interested in any other industries or standards that used glove grip as a specification or attribute. Using the information from the proceedings, we conducted a Google Scholar search for keywords of “grip performance of protective gloves” which included the phrase of "grip performance". It returned 116 results, but many were about grip strength. So, we changed the search to eliminate all literature that included "grip strength". This refined the search to 63 results, but nothing to indicate that grip performance of protective gloves was being measured in any other industry except firefighting.

We conducted another Google Scholar search for "glove grip" AND "protective" to determine research in the general field of glove grip in protective clothing. We received 34 results, but most were a combination of glove grip with other glove attributes, such as dexterity, grip strength, or pinch strength. Therefore, we conducted a search in PubMed using the keyword phrase of "Glove Grip". The search returned 63 results, including the 2012 paper, *Methodology for evaluating gloves in relation to the effects on hand performance capabilities: a literature review.* This paper reviewed 143 research papers from around the world and itemized which papers researched which specific glove attributes in relation to hand performance (Dianat *et al.*, 2012). This document provided insight into the topic and helped in conducting a more refined search of hand, glove, and associated glove attributes and grip characteristics. For example, the combination of glove grip and fine dexterity, such as in parts of Tsaousidis & Andris (1996) was not a concern for our study because we were trying to determine the grip characteristic of a protective glove using gross motor skills. Conversely, also in Tsaousidis & Andris (1996), the combination of glove grip and wrist flexion was of concern based on the ergonomic movements our test subjects were to use.

We also searched those word combinations in Scopus and the Cumulative Index to Nursing and Allied Health Literature (CINAHL). These searches returned many articles from Journals and Proceedings, some of which we already had. Most of these documents, again, focused on glove attributes that were not germane to our study, such as vibration and use of specialized gloves in the treatment of certain hand maladies, and glove permeation of different substances. Although very important attributes of protective gloves, they were not important to this study.

We believed the efforts to find background literature on other test methods for measuring grip characterization, and industries that use grip characterization as a specification were acceptable and thorough. It was clear that this research project should also consider hand performance and other factors that would affect a person's ability to torque both with and without a donned glove. Those factors are addressed individually.

2.3.1 Hand Grip Strength, Hand Torque, and Gloves

Other than the studies already described, studies of human hand torquing ability are typically that of specific tasks and are driven by ergonomics research. For example, a 1998 study used torque strength to determine the effects of handle length, diameter, and orientation in simulated oil rig tasks (Imrhan & Farahmand, 1999). Another study evaluated the factors affecting human torque exertion capabilities when operating valve handwheels (Shih & Wang, 1997a). So, the torque ability used in these papers was that of pronation or supination, such as turning a handle or a wheel valve. The ASTM test method uses a variation of wrist flexion. The difference is that the test method measures the ability of the hand to torque a solid object and not to move an object by using wrist flexion (Decostre *et al.*, 2015; Yoshii *et al.*, 2015). Examples of pronation, supination, and wrist flexion are shown in Figure 2.2 as well as wrist deviations that are other issues with pull-type grip test methods.

Some research on hand performance while wearing protective gloves has centered around how gloves affect grip strength and "breakaway strength"; the point where the hand-handhold coupling is lost. These studies predominantly showed that gloves diminish hand grip strength but that high-friction gloves could increase breakaway strength. Conversely, decreased friction in the hand-handhold coupling reduced a person's breakaway strength (Kovacs *et al.*, 2002; Page *et al.*, 2019; Ramadan, 2017; Shih & Wang, 1997a; Young *et al.*, 2012). In some research, it is believed that tactile sensitivity is a factor in grasping which accounts for these results (Bishu *et al.*, 1994; Tsaousidis & Freivalds, 1998).

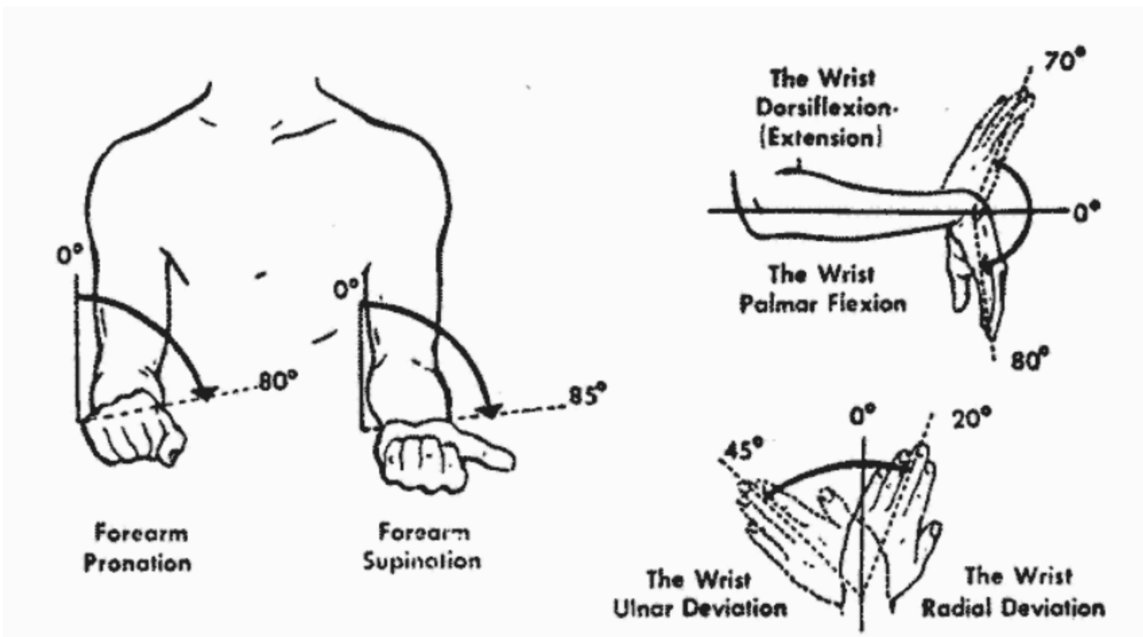


Figure 2.2: Examples of Pronation, Supination, and Wrist Flexion. Source: 38 CFR 4.71

In contrast to the studies on hand strength, studies related to the effects of gloves on torquing ability were not quite as consistent. This is not surprising because a) many tasks use deviated hand, arm, and wrist postures to simulate real-world activities; b) handholds are different sizes, shapes, and materials as well at differing spatial locations; and c) the protective gloves are of differing materials, fabrics, and thicknesses (Axelsson *et al.*, 2018;

Cochran *et al.*, 1988; Imrhan & Farahmand, 1999; Shih & Wang, 1997a, 1997b). This research project aims to control for deviated postures by having the elbow at a 90^o angle and only measuring torque derived by wrist flexion with the wrist at an ergonomically neutral position. We will also use glove styles using two disparate palm and anterior finger surfaces, pig-skin leather, and a proprietary dip coating. These glove models were selected based on previous studies showing both performed well in gripping situations with only a slight difference in grip characterization when dry, but considerable difference when wet (Page *et al.*, 2019; 2020).

Certain hand performance measurements are not pertinent to this research, such as finger dexterity and sub-maximal grasping tasks. This research project does not relate to fine motor skills of the hand, but rather whole hand maximum grasping and torquing abilities that use the larger muscle groups of the forearm and hand. Below is a list of parameters in previous research that were not relevant to this research project and were not pursued:

Test/Task type	**Why not relevant**
Finger Dexterity (such as using controls with a gloved hand vs. bare hand)	Fine manipulation is not part of this study
Dexterity when temperature cold	Fine manipulation is not part of this study. Temperature extremes not part of the study.
Wearing gloves while performing specific tasks like data entry or using a tool.	Effect of gloves on specific tasks not part of this study.
Grasp forces at the sub-maximal level.	This study is for maximal torque generation.
Pinch Grip	This study is for whole hand grasping using maximal torque

2.3.2 Age and Hand Grip Strength

Grip strength is measured using a dynamometer. Anthropometric data, long established in studies worldwide, confirm that grip strength diminishes as a person ages. This is true for both males and females (Gunther *et al.*, 2008). However, it is not a continuous degradation from early adulthood. A Swiss study in 2010 showed that grip strength increased gradually from early career age, plateaued at mid-career age, and diminished in late career. For males, the increase in grip strength from early career to mid-career was approximately 9.2%, then decreased by 14.3% from mid-career to late career ages. For females, the results were 12.5% and 25% respectively (Angst *et al.*, 2010). These results predominantly mirrored the results of a Slovenian study in the same year (Puh, 2010). A study from Korea showed the same parabolic-like gradation by age (Kim *et al.*, 2018). Our study investigated that phenomenon as well.

2.3.3 Sex and Hand Grip Strength

Differences in male and female abilities were common. Typically, female grip strength is about half that of males (Buhman *et al.*, 2000; Gunther *et al.*, 2008; Shih, 2007). Not surprisingly, male grip strength is greater than female grip strength. Although not age-delineated, nor dominant hand-delineated, the National Aeronautical and Space Administration (NASA) showed that males had approximately 40% greater grip strength than females (NASA, 1995). These results were similar to those in the Korean study at 38% (Kim *et al.*, 2018), the Swiss study at 35% (Angst *et al.*, 2010), and the Slovenian study at 39% (Puh, 2010). The NASA information did not specify dominant hand; however, the three comparative studies were for the dominant hand.

2.3.4 Grip and the effect of Handhold Orientation and Size

Research into handhold size has been ongoing since the 1960s as Human Factors became more prevalent in military human-machine interaction studies. Since then, a variety of studies have tried to determine the optimum size and shape of handholds. Understandably, the optimum hand-handhold coupling is not a matter of only size or of only shape. Friction, spatial location, and orientation of the handhold also effect grip. Previous studies on cylindrical handholds showed that maximum grip strength occurs at diameters of approximately 31mm to 38mm (Amis, 1987; Edgren *et al.*, 2004). However, these studies were of grip strength and not the ability to torque. Coupling and friction, as well as grip strength play roles in applying maximum torque.

Handhold orientation, that is the angle at which the handhold is placed for a person to grasp, has been shown to have a significant effect on breakaway strength. Unsurprisingly, orientation that is perpendicular to the force exerted maximizes breakaway strength. As the handhold angle is changed from perpendicular to in-line with the exerted force, the breakaway strength decreases. And, as stated earlier, the more friction between the hand-handhold coupling, the greater the breakaway strength seems to be regardless of handhold orientation (Young *et al.*, 2012).

2.4 Research Gaps

To control as many factors as possible while validating and enhancing the ASTM method, this research project used the ASTM method to limit deviated postures that could influence grip strength as well as torquing ability. We also standardized the rod shape (round), rod material (acrylic), and spatial location (vertical) consistent with the current ASTM method.

This literature review revealed several gaps that we needed to address in our research.

1. Was the previous research using a sample size of five people adequate? We used a larger test population for each step of the research project to help ensure significance.
2. Differences based on age, sex, and hand size were never addressed in the source study. Likewise, the requirement to be able to torque 4.5 to be a qualified test subject was never explained. This disproportionately affected females. We studied all these factors and how they did or did not affect torque and Percent Bare Hand Control Value.
3. The reason for an acrylic rod diameter size of 1.625 in. was never explained in the source study. We decided to use anthropometric data to acquire acrylic rods of varying diameters to investigate how the different sizes impacted torque ability based on age, sex, and hand size.
4. The question of hand grip strength versus torque ability was never addressed in the test method or in any research we found. We believed it important since there could be hand movement inside the glove (hand-glove interface) as well as movement of the glove to the solid surface (glove grip). If a person must grip harder to attain maximum torque, it may contribute to muscle fatigue and accidents. Conversely, if a glove with good grip characteristics reduces muscle fatigue, a person could perhaps work longer or more comfortably.

CHAPTER 3: BARE-HAND TORQUE PERFORMANCE FOR CHARACTERIZING GRIPPING PERFORMANCE OF PROTECTIVE GLOVES

3.1 Abstract

Protective gloves have varying attributes. Our study advances the body of knowledge regarding the attribute of glove grip. We focus on the bare-hand portion of the ASTM F2961-22 test method for characterizing gripping performance of protective gloves. In contrast to earlier studies, our study uses a larger test population, males and females, and varying rod size diameters. Test participants are asked to torque four differing sized rods five times with their bare, self-declared dominant hand. Analysis of results by gender, hand size, Digit3 Link Length determined that the 1.625 in. diameter rod size, as required by the test method, did not have significantly higher torque results than other rod sizes. This was regardless of hand size, Digit 3 Link Length, or gender. However, after further analysis, the 1.625 in. rod size gave the most consistent results between males and females. In addition, we determined that, for bare hands, the test method could reduce the number of iterations to four from the current five iterations.

3.2 Introduction

Personal Protective Equipment (PPE) is vital for worker safety. After examining all other options to mitigate a safety hazard as defined by the *Hierarchy of Controls*, PPE is sometimes the only viable control option (National Institute for Occupational Safety and Health, 2015). The U.S. Occupational Safety & Health Administration (OSHA) requires that employers conduct a PPE assessment and select PPE that will protect workers from identified hazards on the job (Occupational Safety & Health Administration, 2016). Protective gloves are a major component of PPE and are ubiquitous across professions.

The human hand is a complex anatomical structure with capabilities to perform intricate tasks that require fine manipulation and tactile sensitivity (Buhman *et al.*, 2000). It can also perform more robust activities that require a variety of grasping taxonomies (Stival *et al.*, 2019). Gloves are the most reasonable form of physical hand protection when other means of hazard mitigation are impractical. While gloves provide physical protection, they can also either help or hinder hand performance. (Kovacs *et al.*, 2002). From a variety of consensus standards from the American National Standards Institute (ANSI), International Standards Organization (ISO), and European Standards (EN), there are methods to determine glove effectiveness in areas such as cut resistance, abrasion resistance, dexterity, and more. However, there are no known regulations, only one international test method, and one National Fire Protection Association (NFPA) test method to define the grip characterization for protective gloves. Protective gloves can have differing grip capabilities based on the textiles and coatings used in their construction. Moreover, environmental conditions such as temperature, relative humidity, rainfall, and work conditions such as oil contamination will affect the grip characteristics of protective gloves (Imrhan & Farahmand, 1999).

The international test method, ASTM F2961-15 *Test Method for Characterizing Gripping Performance of Gloves Using a Torque Meter,* is referenced in multiple NFPA standards for protective ensembles for firefighting and water rescues. To elucidate, the ASTM term is "Gripping Performance" while in the NFPA standards it is referred to as a "Torque Test" (National Fire Protection Association, 2015, 2016a, 2016b, 2018a, 2018b, 2018c, 2018d, 2020a, 2020b). ASTM F2961 was first published in 2014 using research conducted by Ross, Barker, Watkins, & Deaton and published in the ASTM Proceedings of their 2011 Anaheim Symposia

(Ross *et al.*, 2011). The study described different methods for measuring grip performance of structural firefighting gloves and introduced the torque method incorporated into the ASTM F2961 test method (ASTM International, 2014b). The method was updated in 2015, completed its scheduled review and republished in 2022. The 2015 edition changed the description of the test method to make it clear that a person must grip *and* twist an object rather than just grip it (ASTM International, 2015). The 2022 review was required by ASTM International as part of their systematic updating of standards. The 2022 update allowed the use of different torque meters (ASTM International, 2022b). The test method designates glove grip performance by calculating the "percentage of bare-handed control value" defined as the difference between the average gloved hand torque and bare-handed torque. The higher the percentage, the better the grip performance. This study focuses on the bare-handed torque portion of the test method.

The Ross *et al.* (2011) study that was the basis for the ASTM test method used five participants, four males and one female. The test participants torqued a 1.625 in. diameter acrylic rod five times in succession with one minute rest between each attempt. The study demonstrated that a torque-type test method for evaluating the grip performance of structural firefighter gloves had less subject-to-subject variability and greater range of measured grip ratings than any test method developed by the NFPA at that time. However, we believed a gap existed because of the small sample size (four males, one female), one size of rod (1.625 in.), and requiring five iterations.

Other than Ross *et al.* (2011), studies of human hand torquing ability are typically that of specific tasks and are driven by ergonomics research. For example, a 1998 study used torque strength to determine the effects of handle length, diameter, and orientation in simulated oil rig tasks

(Imrhan & Farahmand, 1999). Another study evaluated the factors affecting human torque exertion capabilities when operating valve handwheels (Shih & Wang, 1997a). So, the torque ability used in these papers was that of pronation or supination, such as turning a handle or a wheel valve. The ASTM test method uses a variation of wrist flexion. The difference is that the test method measures the ability of the hand to torque a solid object and not to move an object by using wrist flexion (Decostre *et al.*, 2015; Yoshii *et al.*, 2015).

Typically, female grip strength is about half that of males (Buhman *et al.*, 2000; Shih, 2007). In addition, studies and anthropometric data confirm that grip strength diminishes as a person becomes older. This is true for both males and females (Gunther *et al.*, 2008). However, it is not a continuous degradation from early adulthood. A Swiss study showed that grip strength increased gradually from early career age, plateaued at mid-career age, and diminished in late career. For males, the increase in grip strength from early career to mid-career was approximately 9.2%, then decreased by 14.3% from mid-career to late career ages. For females, the results were 12.5% and 25%, respectively (Angst *et al.*, 2010). These parabolic-shaped results predominantly mirrored the results of a Slovenian study (Puh, 2010) and a Korean study (Kim *et al.*, 2018). For our study, we have generalized the ages into groups to compare with these previous studies. Since protective gloves are typically used in an industrial environment; we studied working-age (ages 19 - 65) adults. We made three even groups and labeled them “early career” (ages 19 – 35), “mid-career” (ages 36 – 50), and “late career” (ages 51 – 65) for our study. This made it easier to ensure we had an appropriate number of test participants of working-age spectrum.

The literature review did unveil several gaps that we needed to address in this study:

- Statistical significance was questionable based on a source study of only five people. We used a larger test population in this study to help ensure significance.
- Differences based on age, sex, and hand size were never addressed in the source study.
- The reason for an acrylic rod diameter size of 1.625 in. was never explained in the source study. We decided to use anthropometric data to acquire acrylic rods of varying diameters to investigate how the different sizes impacted torque ability based on age, sex, and hand size.

Our overall goal is to enhance the current ASTM test method by using multiple rod sizes, both males and females, and a working-age population. The purpose of this study was to refine key variables: the diameter of the acrylic rod that provided the most consistent mean maximum torque, and the minimum number of iterations that will produce the most consistent mean maximum torque.

3.3 Materials and Methods

This study was approved by the institution's Institutional Review Board (number: 185-21-EP).

3.3.1 Study design

This project used a sequence of experimental studies to validate and enhance the ASTM F2961 Test Method. In this first part, called "Method Optimization" (See Figure 3.1), 68 study participants were asked to torque four acrylic rods of varying diameters with their bare hands. The rod diameters were 1.125 in., 1.375 in., 1.625 in., and 1.875 in. Five iterations were conducted on each rod size. We recorded the maximum torque achieved at each torquing iteration. We, then, compared the mean maximum torque for each rod size based on sex, age, hand girth, and digit3 Link Length. We also determined, based on intrapersonal and interpersonal coefficients of variation, how many iterations were required to obtain consistent results.

Figure 3.1: Sequential process flow of experimentally designed research study. Step One.

3.3.2 Study participants

Study participants were recruited using an 8 ½ in. x 11 in. flyer that could be printed and posted or sent electronically [See Appendix A for flyer]. Study participants in the Omaha, Nebraska, area were the prime targets since the project required in-person testing. Most study participants were recruited through a local safety professional organization, internet advertising, and through personal contacts. Poster indicated the dates and times of testing and contact information to enroll in the study. When a person was interested in participating, the person was directed to an on-line calendar program called "Calendly" (https://calendly.com/) where the person could schedule their testing appointment. To be included in the study, participants had to be between 19 and 65 years old, able to understand English, and not have medical conditions (arthritis, tendonitis, surgery, etc.) that may have prohibited them from standing or using maximum grip strength and hand torque for 20 repetitions within an hour.

3.3.3 On-boarding

After the study participant signed the Informed Consent, they completed the demographic portion of the data collection sheet [see Appendices B and C]. These data points were: 1) age at last birthday, 2) sex at birth, and 3) declared dominant hand. The study proctor then measured the study participant's hand circumference and Digit3 Link Length using a vinyl-coated cloth tape measure (Figure 3.2 shows this on-boarding station where data was collected, and hands measured). The measurement technique followed the *Hand Anthropometry of U.S. Army Personnel* (Greiner, 1991). Measurements were recorded in both inches and centimeters. Numeric hand size was determined based on hand circumference as per the European Standard, DIN EN 420 - Protective gloves – General requirements and test methods (Deutsches Institut für Normung e. V., 2010b). The United States has no similar standard; therefore, the European standard was utilized. The European standard uses the hand circumference, in mm, to determine hand size. The "hand size" is a conventional designation of hand size corresponding to the hand circumference expressed in inches (Deutsches Institut für Normung e. V., 2010a). Our study used both hand size and Digit3 Link length in the data analysis. The European sizing chart was used for male and female

Figure 3.2: On-boarding Station; Step One (Method Optimization). Includes on-boarding instructions (1), data collection forms with randomization (2), and vinyl-coated cloth tape measures (3).

study participants. In contrast to current glove market trends, there is no differentiation as to male and female hand size in the European sizing standard.

3.3.4 Testing protocol

Proctors were given written instructions on how to conduct the testing [See Appendix D]. The test proctor at each station explained the process to the study participant. Each of the four testing stations had a different acrylic rod diameter size (diameter sizes of 1.125 in., 1.375 in., 1.625 in., and 1.875 in.). Torque meters were Param® NJY-40 Digital Torque Testers purchased from LabThink® (Boston, MA). Torque Testers were calibrated according to manufacturer's specifications to 20 Newton-meters (). Calibration was conducted when meters were set in place and prior to removal. The meters and acrylic rods were manufactured by LabThink® (Boston, MA). The sequence with which each study participant completed the stations was randomized.

Figure 3.3: Testing lab. Arrows show the four testing stations of varying rod size.

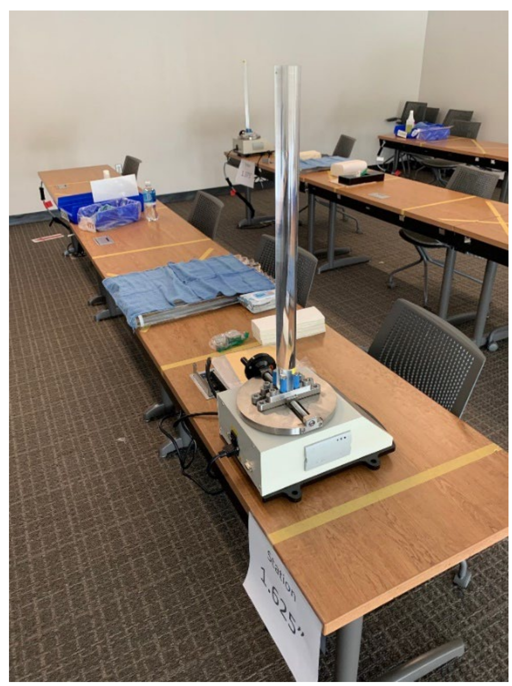


Figure 3.4: Close-up of testing station for 1.625 in. rod size

Study participants used their bare, declared dominant hand to torque the rod as hard as they could for five seconds. Then, they rested for one minute. This torque-rest period was called one iteration. Each station required the study participant to conduct five iterations. Then, the study participant rested for 5 minutes before moving to the next station. This method was consistent with the ASTM method and with accepted biomechanical testing (Chaffin *et al.*, 2006).

Study participants were instructed on the proper body position for the testing prior to the start of the iterations. Study participants were instructed to stand such that they grab the acrylic rod with the elbow bent at a right angle and the upper arm against the side of the body. When needed, proctors adjusted the height of the test apparatus to provide the proper body and arm orientation. Proctors were not allowed to encourage the study participant at any time during the testing; their effort must be their natural maximum effort. To minimize bias, the study participant was not able to observe the reading from the torque meter or learn of the applied torque until all iterations were completed. Figure 3.5 shows the proctor's view of the torque meter while the testing was conducted. The display could only be seen by the proctor while conducting the testing. At the end of five iterations, the meter would print a

Figure 3.5: Proctor's view of 1.125 in. testing station.

summation of the maximum torque achieved for each iteration. This printout was used to verify the data collection sheet and then either provided to the test participant or discarded.

When the study participant completed all iterations at all test stations, the end time was recorded. Start-Stop times were recorded to ensure no wide variations of temperature and humidity took place during a person's testing. In that regard, a data-logging TSI® VelociCalc/Q-Trak 7575 (Shoreview, MN) was used to record room temperature and humidity throughout the testing. Any variations $\pm$ 5°F or ±5% relative humidity during a participant's testing were considered unacceptable. This did not occur during the testing.

3.3.5 Data analysis

Ages of study participants were grouped into early, mid, and late career groups. Early-career included study participants between the ages of 19 and 35. Mid-career was defined as study participants between the ages of 36 and 50, and late career included study participants between the ages of 51 and 65.

Statistical analyses were carried out with IBM SPSS Statistics 28.0 (IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp). Descriptive characteristics, linear regression including General Linear Model – multivariate for comparisons of multiple continuous data components, and coefficients of variation were utilized in the analysis of the data. An alpha value of 0.05 was considered statistically significant.

3.4 Results and Discussion

The demographics of study participants are provided in Table 3.1. Thirty-five males (51.5%) and 33 females (48.5%) participated in this study.

Table 3.1: Descriptive characteristics of participants

Variables	N	%	x̄	σ
Sex				
Female	33	48.5		
Male	35	51.5		
Career Group (age range)				
Early Career (19 – 35)	25	36.8	28.6	±4.9
Mid-Career (36 – 50)	16	23.5	42.4	±5.3
Late Career (51 – 65)	27	39.7	58.7	±5.0
Hand Size (based on circumference)				
7	4	5.9		
8	28	41.2		
9	30	44.1		
10	6	8.8		
Digit3 Link Length (cm)				
< 10.5	26	38.2	10.0	±0.4
10.5 – 11.5	34	50.0	10.9	±0.4
>11.5	8	11.8	11.9	±0.3
Hand Dominance				
Right Hand Dominant	67	98.5		
Left Hand Dominant	1	1.5		

3.4.1 Rod size by hand size and gender

Using a Means Test with ANOVA Table, we found that males had higher torque values ($p<0.001$) than females (Figure 3.6). Torque values for males averaged 4.8 to 7.9 depending on rod size and 3.1 to 5.1 for females. The highest torque value for males and for females was with the 1.875-inch rod. In addition, as male hand size increased, so did the torquing ability, regardless of the rod size. Female torque values, although also increasing by rod size, did not follow the same upward trajectory for hand size as it did for males.

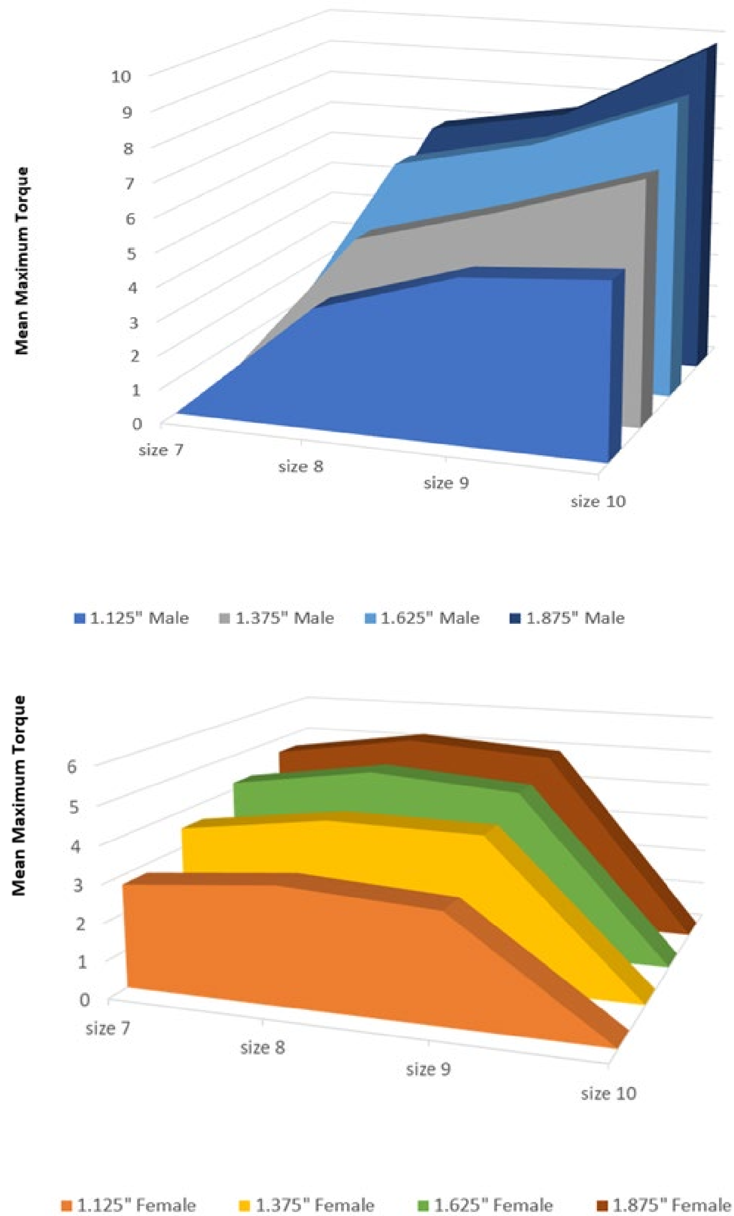


Figure 3.6: Mean Maximum Torque by Sex by Rod Size and by Hand Size
Top = Males
Bottom = Females

There was a significant correlation between hand circumference and mean maximum torque for males ($p < 0.01$). That is to say that as male subjects' hand circumference increased, so did their mean maximum torque. This was not observed for females. Although the mean maximum torque increased as the rod size increased, hand circumference had no significant correlation to that increase.

To determine whether Digit3 Link length is a determining factor in torquing ability, we investigated whether there were significant differences between male and female Digit3 Link length. The mean (± standard deviation) Digit3 Link length was 10.41±0.7 cm in females (n=33) and 11.00±0.7 cm in males (n=35). This small difference was statistically significant ($p<0.05$). This finding is consistent with Greiner (1991).

We found a significant correlation between Digit3 Link length and mean maximum torque for males ($p=0.009$). That is to say that as the male subjects' Digit3 Link length increased, so did their mean maximum torque. This was not observed for females. Although the mean maximum torque increased as the rod size increased, Digit3 Link length had no significant correlation to that increase (Figure 3.7).

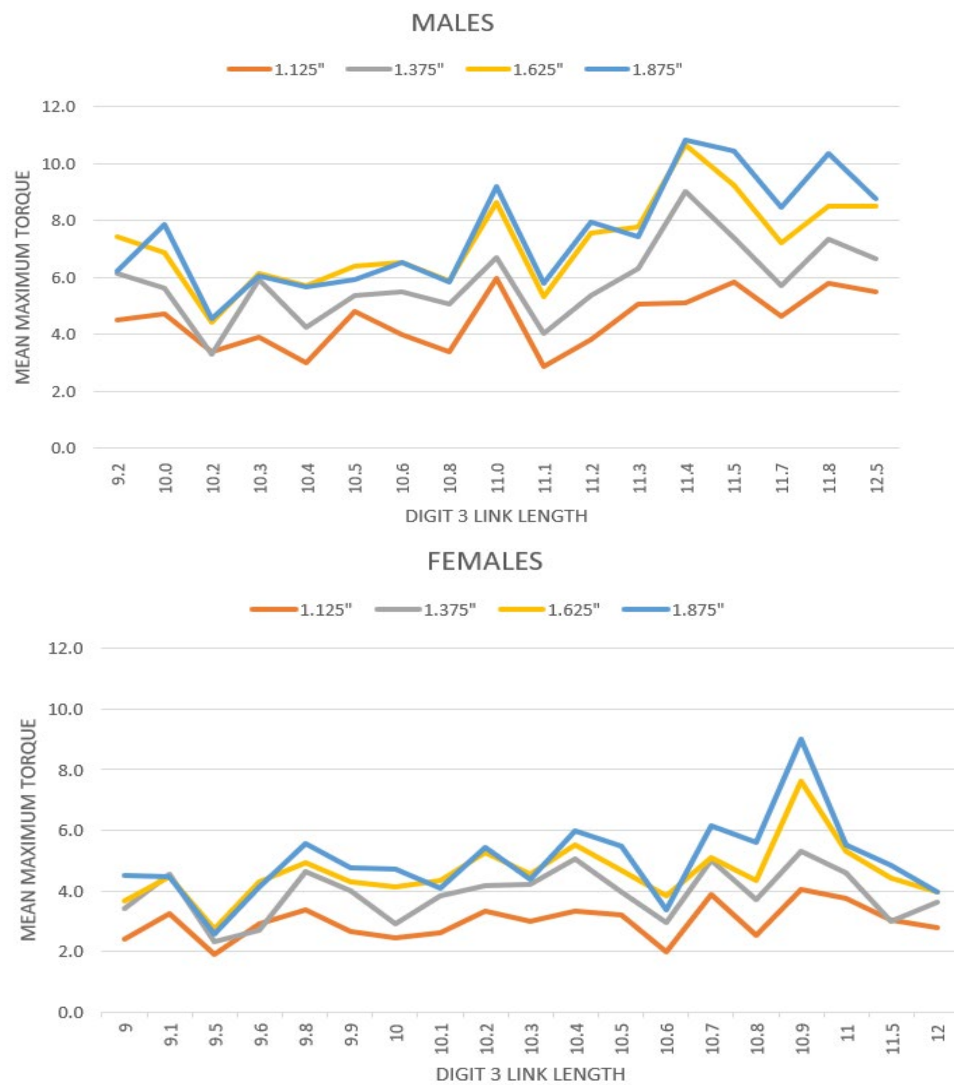


Figure 3.7: Mean-Maximum Torque by Digit3 Link Length by Gender

3.4.2 Determining optimal number of torques

The maximum torque was achieved by the 4th iteration in 84% of male study participants and 87% of female participants. Which illustrates that the mean maximum torque would not increase after 4 iterations in most cases. Table 3.2 shows the maximum iteration number in percentiles. Using this information, we can see that if we wanted to encompass at least 50% of the population, we would need only three iterations of torques to reach the maximum, for 75% of the population, we would need four iterations.

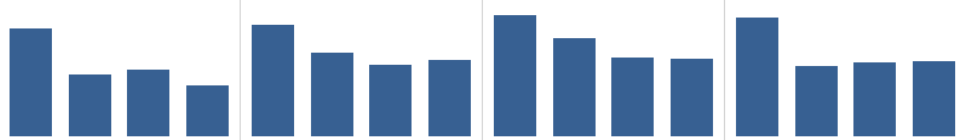
Table 3.2: Number of iterations to achieve maximum torque by rod size

Percentile	**1.125 in.**	**1.375 in.**	**1.625 in.**	**1.875 in.**
n	68	68	68	68
25^{th}	1	1	1	1
50^{th}	2	2.5	2	2
75^{th}	4	4	4	3.75

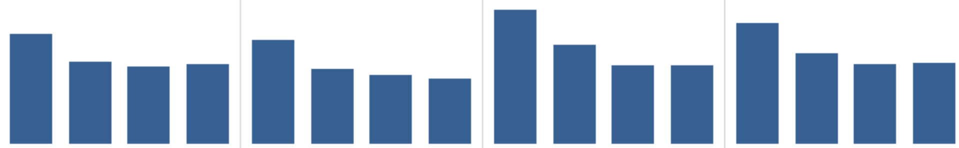
The Coefficient of Variation (CV) of means after 2, 3, 4, and 5 iterations was calculated for each study participant and between study participants. Then, the CVs were compared between males and females. A difference less than 10% between iterations was defined *a priori* to be consistent. Table 3.3 shows the CVs by rod size and by iteration. The 1.125-inch rod did not result in consistency for females by the 5^{th} iteration. The 1.375 in., 1.625 in., and 1.875 in. rods did achieve consistency by the 5^{th} iteration for males and females. It appears that the 1.875 in. rod achieved consistency the fastest for females (3rd iteration) and the 1.125-inch achieved the fastest consistency for males (3rd iteration). Looking at the differences between the male and female data, the 1.625 in. rod shows the most consistent profile between genders.

Table 3.3: Coefficients of Variation by iteration number, by rod size, and sex

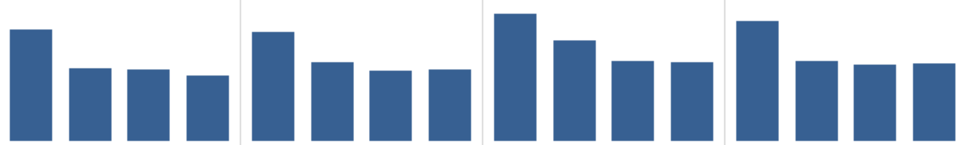
		1.125"				1.375"				1.625"				1.875"			
Sex	Female	CVA2[1]	CVA3[1]	CVA4[1]	CVA5[1]	CVB2[1]	CVB3[1]	CVB4[1]	CVB5[1]	CVC2[1]	CVC3[1]	CVC4[1]	CVC5[1]	CVD2[1]	CVD3[1]	CVD4[1]	CVD5[1]
	N	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
	Std. Deviation	0.077	0.044	0.046	0.037	0.055	0.044	0.039	0.048	0.073	0.062	0.054	0.047	0.060	0.040	0.044	0.040
	Mean	0.101	0.099	0.097	0.104	0.070	0.073	0.077	0.088	0.085	0.088	0.097	0.086	0.071	0.081	0.085	0.075
	CoV	0.766	0.441	0.473	0.358	0.789	0.599	0.512	0.544	0.866	0.702	0.562	0.552	0.848	0.499	0.523	0.532
	%change		-42%	7%	-24%		-24%	-15%	6%		-19%	-20%	-2%		-41%	5%	2%



		1.125"				1.375"				1.625"				1.875"			
Sex	Male																
	N	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
	Std. Deviation	0.057	0.048	0.049	0.052	0.042	0.039	0.036	0.037	0.067	0.049	0.043	0.038	0.064	0.049	0.051	0.046
	Mean	0.072	0.083	0.089	0.092	0.057	0.073	0.074	0.080	0.070	0.069	0.077	0.069	0.075	0.076	0.089	0.079
	CoV	0.786	0.584	0.554	0.573	0.743	0.533	0.488	0.461	0.959	0.705	0.561	0.558	0.861	0.643	0.570	0.574
	%change		-26%	-5%	3%		-28%	-8%	-5%		-26%	-21%	0%		-25%	-11%	1%



	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
	Std. Deviation	0.068	0.047	0.048	0.046	0.049	0.041	0.037	0.042	0.070	0.056	0.050	0.043	0.062	0.045	0.048	0.043
	Mean	0.086	0.091	0.093	0.098	0.063	0.073	0.075	0.084	0.077	0.078	0.087	0.077	0.073	0.079	0.087	0.077
	CoV	0.796	0.513	0.511	0.469	0.776	0.562	0.497	0.505	0.908	0.714	0.572	0.564	0.849	0.570	0.546	0.552
	%change		-36%	0%	-8%		-28%	-12%	2%		-21%	-20%	-1%		-33%	-4%	1%



[1] – Coding explanation: CV = Coefficient of Variation | A=Rod Size 1.125 in. | B=Rod Size 1.375 in. | C=Rod Size 1.625 in. | D=Rod Size 1.875 in. | 2=after 2 iterations | 3=after 3 iterations | 4=after 4 iterations | 5=after 5 iterations

3.5 Conclusions

In this study, we ensured the basics of the *F2961-22 Test Method for Characterizing Gripping Performance of Protective Gloves* were correct. This included ensuring the rod size was correct regardless of a person's sex, age, and hand size. We also started the investigation to ensure the number of required iterations was correct.

Our study showed that as the rod size increased, the torque values increased for males and females. The 1.625 in. diameter rod currently used in the ASTM F2961-22 Standard Test Method, while not providing the highest amount of torque for males and females, provided the most consistent results between the two. The consistency profile of the 1.625 in. rod between males and females was the most similar compared to all other rod sizes.

The highest torque value was achieved by 50% of the test participants by the 3rd iteration and by 75% of the test participants by the 4th iteration. In addition, by the 4th iteration, consistency was achieved in rod sizes 1.375 in., 1.625 in., and 1.875 in. regardless of gender. This indicates that the test method, if only for bare hands, could reduce the number of iterations to four rather than the current five iterations. This may not be the case when comparing bare to gloved hands, which is the purpose of the ASTM F2961-22 Standard Test Method.

This research is the first step in fully validating ASTM F2961-22 Standard Test Method. One of the strengths of this study as compared to earlier studies is the number of test participants. However, we did not record detailed participant demographics to see if our test population could be generalized to the greater population. This study was conducted in Omaha, Nebraska, and test participants were mostly students at the University or nearby residents. We had ethnic diversity in our test sample, but we cannot say that our results can be generalized to the general public in that regard. Had we ensured that our test sample reflected the demographics of the country, we might have had somewhat different results; although it is unclear whether that would have an impact on the validity of the ASTM Test Method.

Follow-on research will include conducting the test as described in the standard with bare and gloved hands and using a larger population of working aged males and females. Then, we can determine if age or gender affects the Percent Bare Hand Control Value (%BHCV). In addition, the current method requires the test subject to be able to torque 4.5 with their bare hand. This requirement may disproportionately impact females. Follow-on research could determine if that requirement is necessary. Also, with more research, we could determine if some sort of normalization factor should be used to give consistent results between male and females and by age. Lastly, more research is needed to understand the impact that water or oil have on the grip characteristics of protective gloves. This is especially important for occupations that expose workers to inclement weather or to oily or greasy environments.

CHAPTER 4: CHARACTERIZING GRIPPING PERFORMANCE OF PROTECTIVE GLOVES USING THE ASTM F2961-22 METHOD

4.1 Abstract

Protective gloves have varying attributes. Our study advances the body of knowledge regarding the attribute of glove grip. We focused on the test method of ASTM F2961-22 but used a larger test population, males and females, and two disparate glove samples. Test participants were asked to torque an acrylic rod five times with their bare, self-declared dominant hand, then again with a leather glove, and again with a polymer dipped glove. Results show that age, sex, and hand size were not factors in getting valid percent Bare Hand Control Value (%BHCV), defined as the percentage of mean maximum torque of gloved hand divided by the mean maximum torque of bare hands. The test method of ASTM F2961-22 is correct as written except for 1) requiring a test subject to be able to torque 4.5 with their bare hand; and 2) using a minimum of three test subjects. We found that the 4.5 requirement was unnecessary and would disproportionately impact females. In addition, using four test subjects would return more accurate results without a considerable increase in cost.

4.2 Introduction

When it comes to protective gloves, there are many consensus standards to determine a wide variety of attributes and characteristics. To name just a few, ANSI/ISEA 105-2016 addresses the classification and testing of protective gloves for cut-resistance, puncture resistance, abrasion resistance, chemical permeation resistance, and more (ANSI/ISEA, 2016). The European Union has published a number of consensus standards associated with protective glove characteristics. For example, BS EN 388:2016 addresses the classification and testing of mechanical risks such as abrasion, cut, tear, puncture resistance and impact protection (British Standards Institution, 2016). However, there are no regulations, only one international test method, and one National Fire Protection Association (NFPA) test method to define the grip characterization for protective gloves.

Protective gloves can have differing grip capabilities based on the textiles and coatings used in their construction. Moreover, environmental conditions such as temperature, relative humidity, rainfall, and work conditions such as oil contamination will affect the grip characteristics of protective gloves (Imrhan & Farahmand, 1999). The international test method, ASTM F2961-15 *Test Method for Characterizing Gripping Performance of Gloves Using a Torque Meter*, is referenced in multiple NFPA standards for protective ensembles for firefighting and water rescues. However, in those standards, it is referred to as a “Torque Test” (National Fire Protection Association, 2015, 2016a, 2016b, 2018a, 2018b, 2018c, 2018d, 2020a, 2020b). ASTM F2961 was first published in 2014 using the research conducted at North Carolina State University and published in the ASTM Proceedings of their 2011 Anaheim Symposia (Ross *et al.*, 2011). The study described different methods for measuring grip performance of structural firefighting gloves and introduced the torque method incorporated into the ASTM F2961 test method (Ross *et al.*, 2011). The method was updated in 2015, completed its scheduled review and republished in 2022. The 2015 edition changed the description of the test method to make it clear that a person must grip and twist an object rather than just grip it (ASTM International, 2015). The 2022 review was required by ASTM International as part of their systematic updating of standards. The 2022 update allowed the use of different torque meters (ASTM International, 2022b). The test method designates glove grip performance by calculating the “percentage of bare-handed control value” defined as the difference between the average gloved hand torque and bare-handed torque. The higher the percentage, the better the grip performance.

The Ross *et al.* (2011) study that was the basis for the ASTM test method used five participants, four males and one female. The test participants torqued a 1.625 in. diameter acrylic rod five times in succession with one minute rest between each attempt. The study demonstrated that a torque-type test method for evaluating the grip performance of structural firefighter gloves had less subject-to-subject variability and greater range of measured grip ratings than any test method developed by the NFPA at that time. However, we thought a gap existed because of the small sample size (four males, one female); one size of rod (1.625 in.); and a defined number of iterations (5).

In our previous study outlined in Chapter 3, we determined that the rod size of 1.625 in. was consistent with males and with females, as well as between males and females. Therefore, this study used that rod size for all torque iterations. We also determined that four iterations for bare hand torquing was sufficient to give consistent results. However, for this part of the study, we continued to use five iterations because we will be studying bare hand and gloved hand torque.

Our overall goal is to enhance the current ASTM test method by using a larger population of working age males and females. The purpose of this study was to determine whether age or gender affects the Percent Bare Hand Control Value (%BHCV). In addition, the current method requires the test subject to be able to torque 4.5 with their bare hand. This requirement may disproportionately impact females. We determined whether that requirement is necessary. We also tried to determine whether some sort of normalization factor should be used to give consistent results between males and females of different ages.

4.3 Materials and Methods

This study was approved by the institution's Institutional Review Board (number: 185-21-EP).

4.3.1 Study design

This project used a sequence of experimental studies to validate and enhance the ASTM F2961 Test Method. In this second part, called "Grip Performance" (See Figure 4.1), 85 study participants were asked to torque a 1.625 in. diameter acrylic rod with their bare, self-declared dominant hand. In addition, those participants donned a leather glove and a synthetic dipped glove and were asked to torque the rod. Five iterations each were conducted for the bare hand, the leather glove, and the synthetic dipped glove. Sequence was randomized but the test participant completed the five iterations for each situation before going to the next. We recorded the maximum torque achieved at each torquing iteration. Then, as shown in Equation 4.1, we calculated the Percent Bare Hand Control Value as described in the ASTM F2961-22 Test Method:

$$\frac{T_G}{T_B} \times 100 = \%BHCV$$

Equation 4.1: ASTM F2961-22 Bare Hand Control Value formula

where:

%BHCV = percentage of bare-handed control value,

T_G = average maximum torque applied with gloved hand, and

T_B = average maximum torque applied with bare hand.

Values higher than 100 %BHCV indicate that the glove enhances the wearer's ability to grip a solid object while values lower than 100 % decreases the wearer's ability to grip a solid object (ASTM International, 2022b).

The gloves used in this study were the MCR Safety (Collierville, TN) Ninja® Ice model N9690 dipped in a proprietary synthetic dip called HPT™ (referred to as "HPT glove" in this study), and Orr Safety Corporation (Louisville, KY) Drivers Glove, model ORRFB570 (referred to as "Leather glove" in this study).

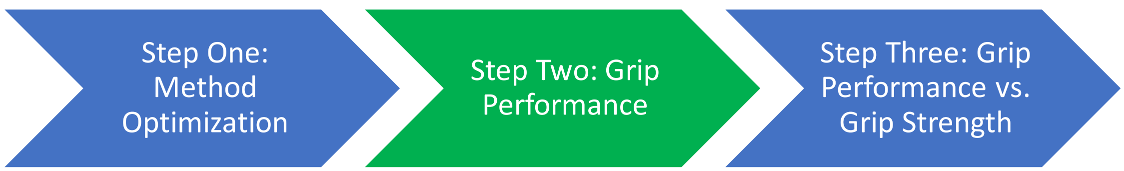


Figure 4.1: Sequential process flow of experimentally designed research study. Step Two.

4.3.2 Study participants

Study participants were recruited using an 8 ½ in. x 11 in. flyer [See Appendix E] that could be printed and posted or sent electronically. Study participants in the Omaha, Nebraska, area were the prime targets since the project required in-person testing. Most study participants were recruited through a local safety professional organization, internet advertising, and through personal contacts. Posters indicated the dates, times, and location of testing and contact information to enroll in the study. When a person was interested in participating, the person was directed to an on-line calendar program called "Calendly" (https://calendly.com/) where the person could schedule their testing appointment. To be included in the study, participants had to be between 19 and 65 years old, able to understand English, and not have medical conditions (arthritis, tendonitis, surgery, etc.) that might prohibit them from standing or using maximum grip strength and hand torque for 20 repetitions within an hour.

For our study, we generalized the ages into groups to compare with previous studies. Since protective gloves are typically used in an industrial environment; we studied working-age (ages 19 - 65) adults. We made three even groups and labeled them “early career” (ages 19 – 35), “mid-career” (ages 36 – 50), and “late career” (ages 51 – 65) for our study. This made it easier to ensure we had an appropriate number of test participants of working-age spectrum.

4.3.3 On-boarding

After the study participant signed the Informed Consent, they completed the demographic portion of the data collection sheet [See Appendices F and G]. These data points were: 1) age at last birthday, 2) sex at birth, and 3) declared dominant hand. The study proctor then measured the study participant’s hand circumference and Digit3 Link Length using a vinyl-coated cloth tape measure. The measurement technique followed the *Hand Anthropometry of U.S. Army Personnel* (Greiner, 1991). Measurements were recorded in both inches and centimeters. Numeric hand size was determined based on hand circumference as per the European Standard, DIN EN 420 - Protective gloves – General requirements and test methods (Deutsches Institut für Normung e. V., 2010b). The United States has no similar standard; therefore, the European standard was utilized. The European standard uses the hand circumference, in mm, to determine hand size. The “hand size” is a conventional designation of hand size corresponding to the hand circumference expressed in inches

(Deutsches Institut für Normung e. V., 2010a). Our study used both hand size and Digit3 Link length in the data analysis. The European sizing chart was used for male and female study participants. The randomized sequence of testing was also written on the data collection sheet to inform the test participant and the test proctor.

4.3.4 Testing protocol

All gloves were conditioned at a temperature of 21 ± 3°C (70 ± 5°F) and a relative humidity of 65 ± 5% for at least 24 hours (See Figures 4.2 and 4.3). This was accomplished by hanging all pairs of test gloves inside the Environmental Testing Chamber at the Peter Kiewit Institute, University of Nebraska Durham School of Architectural Engineering & Construction, Scott Campus in Omaha, Nebraska. The chamber, built specially by Climatic Testing Systems (CTS), provides a tightly controlled thermal environment, while also controlling humidity at any level. The temperature is controlled to within ±0.1 °F. It has a steam humidification system and uses a refrigeration system to remove humidity and

Figure 3.2: (Above) Exterior view of Environmental Testing Chamber

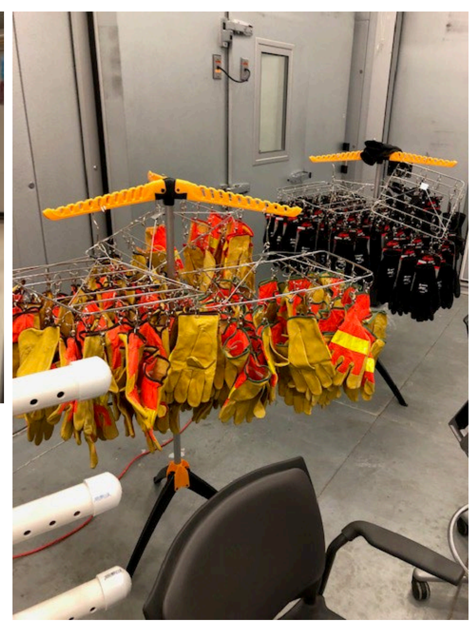


Figure 4.3: (Right) Interior view of environmental chamber with glove samples being conditioned

provide cooling, with heating provided by electrical heaters. All test subjects conducted their torque iterations while inside the chamber.

Proctors were given written instructions on how to conduct the testing. The test proctor explained the process to the study participant. We erected four identical testing stations to be able to test four subjects at one time. Each station had a torque meter equipped with a 1.625 in. acrylic rod diameter size. Torque meters were Param® NJY-40 Digital Torque Testers purchased from LabThink® (Boston, MA). Torque Testers were calibrated according to manufacturer's specifications to 20 Newton-meters (). Calibration was conducted when meters were set in place and prior to removal. The meters and acrylic rods were manufactured by LabThink® (Boston, MA).

The sequence with which each study participant completed the testing was randomized using random.org on-line program.

Study participants used their declared dominant hand to torque the rod as hard as they could for five seconds. Then, they rested for one minute. This torque-rest period was called one iteration. Each study participant conducted five iterations and then rested for five minutes before going to the next sequence item. Therefore, a person would torque five iterations of the first sequence item (i.e. bare hand, leather gloved hand, or donned HPT glove), rest for five minutes, then torque five iterations of the next sequence item, rest for five minutes, then torque five iterations of the final sequence item. This method was consistent with the ASTM method and with accepted biomechanical testing (Chaffin *et al.*, 2006).

Study participants were instructed on the proper body position for the testing prior to the start of the iterations. Study participants were instructed to stand such that they grab the acrylic rod with the elbow bent at a right angle and the upper arm against the side of the body. When needed, proctors adjusted the height of the test apparatus to provide the proper body and arm orientation. Proctors were not allowed to encourage the study participant at any time during the testing; their effort must be their natural maximum effort. To minimize bias, the study participant was not able to observe the reading from the torque meter or learn of the applied torque until all iterations were completed. In addition, study participants were instructed to remove the glove between iterations to help control for temperature fluctuations caused by body heat. Each study participant was given a new pair of each style of glove. Gloves were not reused.

When the study participant completed all iterations for the bare and gloved hand, the end time was recorded. Start-Stop times were recorded to ensure no wide variations of temperature and humidity took place during a person’s testing in the event of a failure of the environmental chamber. That did not occur and there were no variations of temperature or humidity outside the parameters of the test method.

4.3.5 Data analysis

Ages of study participants were grouped into early, mid, and late career groups. Early-career included study participants between the ages of 19 and 35. Mid-career was defined as study participants between the ages of 36 and 50, and late career included study participants between the ages of 51 and 65.

Statistical analyses were carried out with IBM SPSS Statistics 28.0.0 (IBM Corp. Released 2021. IBM SPSS Statistics for Windows, Version 28.0.0. Armonk, NY: IBM Corp). Descriptive characteristics, linear regression including General Linear Model – multivariate for comparisons of multiple continuous data components, and coefficients of variation were utilized in the analysis of the data. An alpha value of 0.05 was considered statistically significant.

4.4 Results and Discussion

The demographics of study participants are provided in Table 4.1. Forty-two males (49.4%) and 43 females (50.6%) participated in this study.

Table 4.1: Descriptive characteristics of participants

Variables	N	%	x̄	σ
Sex				
Female	43	50.6		
Male	42	49.4		
Career Group (age range)				
Early Career (19 – 35)	32	37.6	28.7	±4.4
Mid-Career (36 – 50)	24	28.2	42.4	±5.0
Late Career (51 – 65)	29	34.1	58.1	±5.3
Hand Size (based on hand circumference (EU#))				
7	3	3.5		
8	36	42.4		
9	34	40.0		
10	12	14.1		
Digit3 Link Length (cm)				
< 10.5	49	57.7	9.9	±0.4
10.5 – 11.5	29	34.1	10.9	±0.3
>11.5	7	8.2	11.9	±0.4
Hand Dominance				
Right Hand Dominant	81	95.3		
Left Hand Dominant	4	4.7		

4.4.1 Analysis by age

We found no evidence that age was a factor in the mean maximum torque achieved by males or females. This was true of Bare Hand, Leather gloved hand, and donned HPT glove. It was also true of the %BHCV. Table 4.2 summarizes the mean maximum torque by sex and by age group for each situation. The %BHCV is the average of the participants' %BHCV as instructed in the ASTM Test Method.

Table 4.2: Summary of Mean Maximum Torque and %BHCV by Age Group by Sex

		n	**Mean Maximum Torque Bare Hand ()**	**Mean Maximum Torque Leather Glove () / %BHCV (%)**	**Mean Maximum Torque HPT Glove () / %BHCV (%)**
Female	Early Career	18	4.18	3.53 / 97.11	4.72 / 116.26
	Mid-Career	12	5.08	4.42 / 88.30	6.06 / 120.61
	Late Career	13	4.47	3.89 / 89.15	5.15 / 117.49
	Significance to age (p-value)		0.200	0.142 / 0.807	0.094 / 0.898
Male	Early Career	14	6.98	5.70 / 81.35	7.66 / 110.19
	Mid-Career	12	7.37	6.42 / 88.69	8.38 / 115.60
	Late Career	16	6.73	6.33 / 98.08	7.76 / 120.42
	Significance to age (p-value)		0.626	0.444 / 0.130	0.518 / 0.432

4.4.2 Analysis by sex

As noted in Chapter 3, we found that males had higher torque values than females. This finding was statistically significant ($p < 0.001$). This second study confirmed that finding ($p<0.001$). In addition, in our first step, we found that there was a significant correlation between hand circumference and mean maximum torque for males ($p < 0.01$). That is to say that as male subjects' hand circumference increased, so did their mean maximum torque. This was not the same for females. This second study confirmed that finding; as males hand circumference increased, so did their torquing ability in Bare Hand, Leather gloved hand,

and donned HPT glove (p=0.006, p=0.003, and p=0.033, respectively). In the previous study, there was no significant correlation for females. In this study, we found significance of hand circumference and torquing ability only in the Leather glove (p=0.035). Bare Hand and donned HPT glove showed reduced or no significance (p=0.056 and p=0.216 respectively).

To determine whether Digit3 Link length is a determining factor in torquing ability, we investigated if there were significant differences between male and female Digit3 Link length. In our previous study, we found a small, but significant difference in male versus female Digit3 Link length. This study confirmed that earlier finding. The mean (± standard deviation) Digit3 Link length was 10.10 ± 0.58 cm in females (n=43) and 11.68 ± 0.79 cm in males (n=42). This small difference was statistically significant (p<0.001). This finding is also consistent with Greiner (1991).

For this study, as shown in Table 4.3, our findings showed that the mean, maximum torque versus Digit3 Link length showed significance for males but not for females. This was the same for Bare Hand, Leather Gloved hand, and donned HPT-dipped glove.

Table 4.3: Mean maximum torque versus Digit3 Link Length and p-value

	n	**Mean Maximum Torque Bare Hand versus Digit3 Link Length (p-value)**	**Mean Maximum Torque Leather Glove versus Digit3 Link Length (p-value)**	**Mean Maximum Torque HPT Glove versus Digit3 Link Length (p-value)**
Females	43	4.520 (p=0.07)	3.889 (p=0.172)	5.222 (p=0.342)
Males	42	6.995 (p=0.013)	6.149 (p=0.003)	7.905 (p=0.005)

Because males can torque more than females, we investigated what that would do to the %Bare Hand Control Value. Table 4.4 shows that female results are slightly higher than males; however, there was no significance to the difference.

Table 4.4: Percent Bare Hand Control Value by sex by glove type

	n	**%BHCV – Leather Glove**	**%BHCV – HPT Glove**
Females	43	92.24	117.84
Males	42	89.82	115.63
p-value		p=0.736	p=0.661

4.4.3 Determining optimal number of torques

In this study we were looking at the %BHCV and not, specifically on the torque measurements of the bare hand or on a particular gloved hand, but on the ratio between the two. Therefore, we thought that the Coefficient of Variation should be of the %BHCV and not each situation (Bare Hand, Gloved Hand). That data for each of those situations is in the Supplement.

The Coefficient of Variation for the %BHCV for males and for females is shown in Table 4.5. The graph shows the Coefficient of Variation for the iterations indicated. As in our last study, a difference less than 10% between iterations was defined *a priori* to be consistent. In most cases, the Coefficient of Variation met the consistency definition by the 4th iteration, and all met it by the 5th iteration.

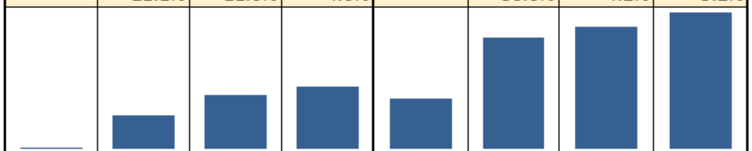
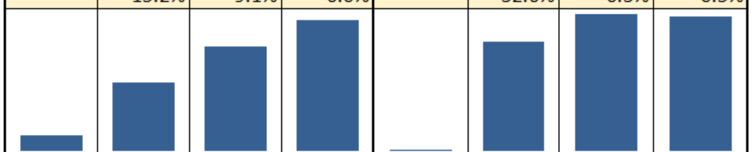
Table 4.5: Coefficient of Variation, %Bare Hand Control Value by Sex by Glove Type

		Leather				HPT			
	n	CV_LTH2[1]	CV_LTH3[1]	CV_LTH4[1]	CV_LTH5[1]	CV_HPT2[1]	CV-HPT3[1]	CV_HPT4[1]	CV_HPT5[1]
F	43	0.052	0.065	0.069	0.071	0.065	0.083	0.087	0.092
			-24.2%	-6.4%	-3.2%		-27.4%	-4.7%	-6.7%
M	42	0.052	0.059	0.066	0.070	0.056	0.071	0.074	0.074
			-13.8%	-11.4%	-6.6%		-28.0%	-4.5%	0.8%
Total	85	0.052	0.062	0.067	0.071	0.060	0.077	0.081	0.083
			-19.1%	-8.7%	-4.8%		-27.7%	-4.6%	-3.3%

[1] – Coding explanation: CV = Coefficient of Variation | LTH = Leather Glove | HPT = HPT Glove | 2=after 2 iterations | 3=after 3 iterations | 4=after 4 iterations | 5=after 5 iterations

The ASTM F2961-22 Test Method requires that a test subject must be able to torque 4.5 to conduct the measurement for %BHCV. Therefore, we removed those test subjects from our data and recalculated the Coefficient of Variation. Removing those study participants who could not torque at least 4.5 did not appear to create any better consistency as it pertained to %BHCV as shown in Table 4.6.

Table 4.6: Coefficient of Variation, %Bare Hand Control Value by Sex by Glove Type; 4.5 N m minimum ability

		Leather				HPT			
	n	**CV_LTH2[1]**	**CV_LTH3[1]**	**CV_LTH4[1]**	**CV_LTH5[1]**	**CV_HPT2[1]**	**CV-HPT3[1]**	**CV_HPT4[1]**	**CV_HPT5[1]**
F	**31**	0.042	0.051	0.056	0.058	0.055	0.072	0.075	0.079
			-21.1%	-11.0%	-4.0%		-30.0%	-4.2%	-5.2%
									
M	**40**	0.052	0.060	0.066	0.069	0.050	0.066	0.070	0.070
			-15.2%	-9.1%	-6.0%		-32.6%	-6.3%	0.5%
									
Total	**71**	0.048	0.056	0.061	0.065	0.052	0.069	0.072	0.074
			-17.4%	-9.8%	-5.2%		-31.4%	-5.3%	-2.1%
									

[1] – Coding explanation: CV = Coefficient of Variation | LTH = Leather Glove | HPT = HPT Glove | 2=after 2 iterations | 3=after 3 iterations | 4=after 4 iterations | 5=after 5 iterations

4.4.4 Determining optimal number of test subjects

ASTM F2961-22, requires a minimum of three test subjects with similar hand sizes to conduct the test. Our data suggest that this should be increased to four test subjects; and, although it is a good idea to have similar hand size for ease of testing procedures, there is no significance to the %BHCV result.

After looking at the intrapersonal coefficient of variation, we investigated the Variability Estimate of groups of test subjects. These groups were randomly selected 3-person, 4-person, and 5-person groups. Randomization was accomplished using Microsoft® Excel®.

Then, %BHCV data from the selected test subjects was put into SPSS Mixed Model of Linear Auto-Regression (AR1) to determine the variability estimate of that group. Thirty samples of each group size and each glove type were randomly selected and analyzed. Figures 4.4 and 4.5 show the boxplot of the variability estimates. Figure 4.6 shows a clustered error bar chart of the combined information. The charts indicate that four randomly selected test subjects have a tighter variability in the %BHCV of both leather and HPT gloves. We only examined groups up to five people because this is a test method and there is a diminishing return when requiring more test subjects.

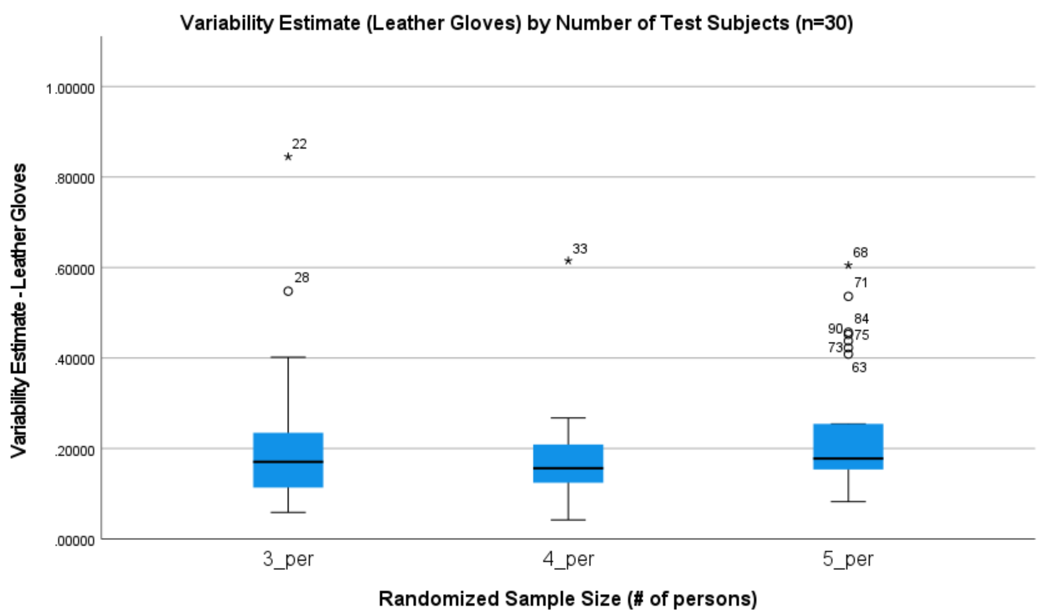


Figure 4.4: Variability Estimate - Leather Gloves

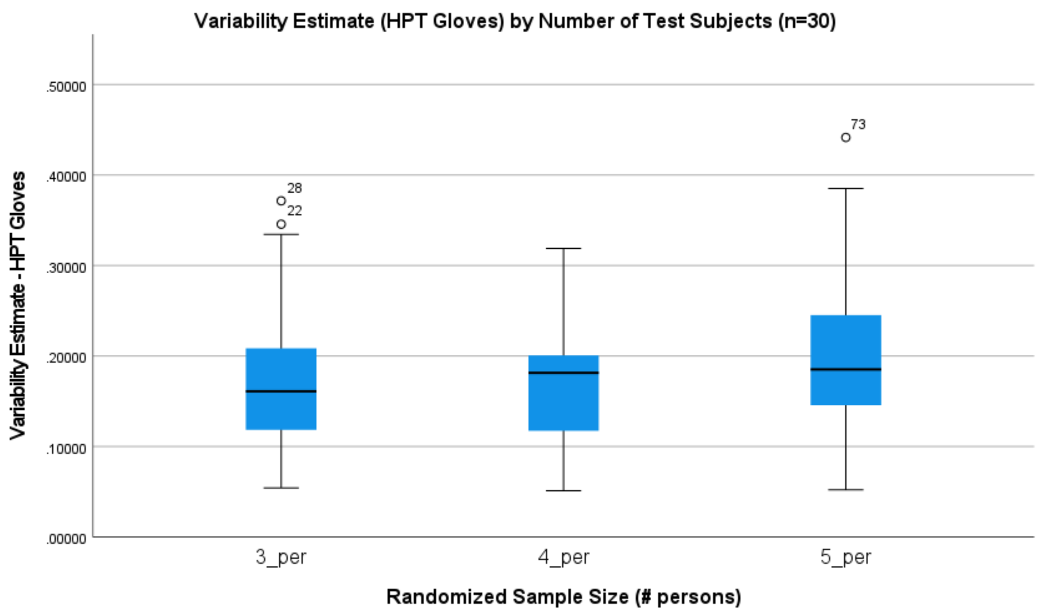


Figure 4.5: Variability Estimate - HPT Gloves

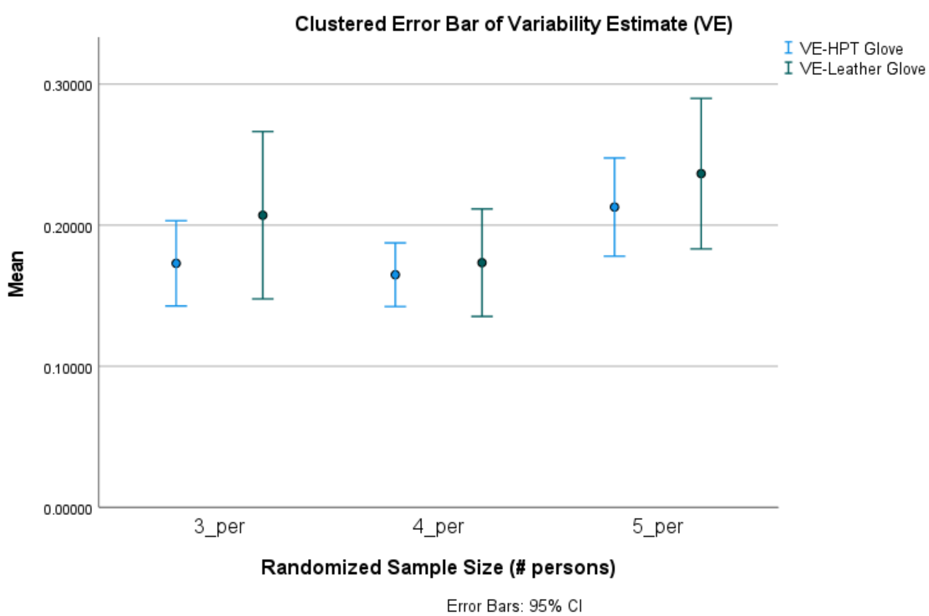


Figure 4.6: Clustered Error Plot of Variability Estimate for HPT and Leather Gloves

4.5 Conclusions

Our hypothesis was that the %BHCV would be significantly different for males than for females. That was not the case. Although females had a higher %BHCV than males for the two types of gloves studied, the difference was not significant, and the test for correlation showed no correlation due to sex.

Our hypothesis was that age would have an impact on the %BHCV. This, also, was not the case. There was no significant difference in %BHCV between age groups.

We hypothesized that differences in torquing ability would have an impact on %BHCV. When we removed the data for participants that could not torque at least 4.5 ; the consistency remained similar.

We also determined that four test subjects for the Test Method would result in better results than only three. Hand size, although a significant factor for males in how much they can torque, it was insignificant when calculating Percent Bare Hand Control Value.

In summary, we find that using five iterations of torquing as is described in ASTM F2961-22 is correct; all %BHCV tests were consistent by the 5th iteration. We find that requiring a test subject to torque at least 4.5 is not necessary and could disproportionately exclude females as test subjects.

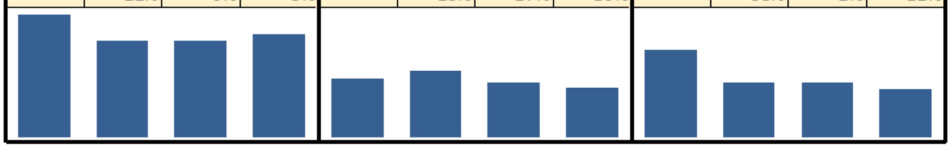
This research was a second step in fully validating the ASTM F2961-22 Standard Test Method. Follow-on research will include determining whether the glove type used in this testing required the test subject to grasp the acrylic rod harder (measurement of grip strength vs torquing ability). Many times, the hand will move inside the glove when performing tasks of this nature. If a glove has great grip performance, but it causes a person to grip stronger, muscle fatigue could be experienced. After the completion of analyzing grip performance of dry gloves, we may be able to use this test method on gloves that are wet with water or wet with oil. The test method could then be used to inform consumers on the characteristics of glove grip before purchasing a protective glove. This would be a benefit to those occupations that involve exposure to wet or damp environments, such as inclement weather or exposure to oily or greasy environments.

4.6 Supplemental Information

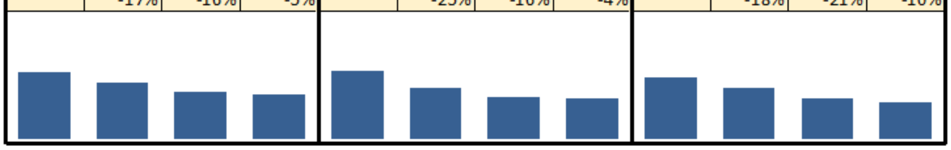
In our prior study, we found that four torque iterations would be acceptable for Bare Hand measurements. But we decided to follow the current test method for this study since we were also using gloved hands. Consistent with our last study, the Bare Hand iterations were consistent at the 4th iteration. However, for females, Table 4.7 shows that the consistency guideline of no more than 10% change in the Coefficient of Variation (CV) was not met with the HPT glove.

Table 4.7: Coefficient of Variation for Bare Hand, Leather, and HPT gloves – Mean Maximum Torque, Full Test Population

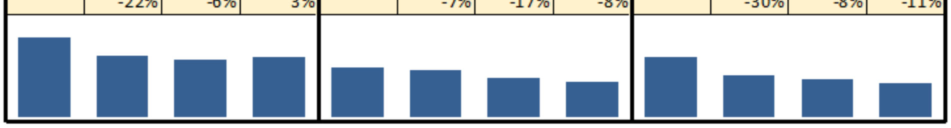
		Bare Hand				Leather				HPT			
Sex	Female	CVBH2	CVBH3	CVBH4	CVBH5	CVLTH2	CVLTH3	CVLTH4	CVLTH5	CVHPT2	CVHPT3	CVHPT4	CVHPT5
	N	43	43	43	43	43	43	43	43	43	43	43	43
	Std. Deviation	0.111	0.093	0.115	0.124	0.051	0.062	0.052	0.047	0.095	0.065	0.066	0.059
	Mean	0.076	0.082	0.101	0.101	0.074	0.079	0.080	0.079	0.092	0.101	0.100	0.103
	CoV	1.455	1.141	1.140	1.227	0.696	0.788	0.653	0.587	1.038	0.644	0.656	0.575
	%change		-22%	0%	8%		13%	-17%	-10%		-38%	2%	-12%



	Bare Hand				Leather				HPT			
Male												
N	42	42	42	42	42	42	42	42	42	42	42	42
Std. Deviation	0.042	0.04379	0.049	0.04864	0.060	0.04433	0.039	0.03854	0.058	0.05312	0.042	0.03598
Mean	0.051	0.06505	0.087	0.09093	0.074	0.07264	0.076	0.07874	0.079	0.08713	0.086	0.08249
CoV	0.812	0.673	0.564	0.535	0.817	0.610	0.511	0.489	0.743	0.610	0.484	0.436
%change		-17%	-16%	-5%		-25%	-16%	-4%		-18%	-21%	-10%



N	85	85	85	85	85	85	85	85	85	85	85	85
Std. Deviation	0.077	0.069	0.082	0.087	0.056	0.054	0.046	0.043	0.077	0.059	0.054	0.048
Mean	0.064	0.073	0.094	0.096	0.074	0.076	0.078	0.079	0.085	0.094	0.093	0.093
CoV	1.200	0.936	0.876	0.904	0.756	0.704	0.584	0.539	0.903	0.629	0.577	0.514
%change		-22%	-6%	3%		-7%	-17%	-8%		-30%	-8%	-11%

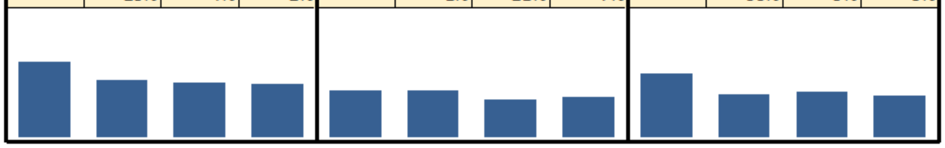


Coding explanation: CV = Coefficient of Variation | BH = Bare Hand | LTH = Leather Glove | HPT = HPT Glove | 2=after 2 iterations | 3=after 3 iterations | 4=after 4 iterations | 5=after 5 iterations

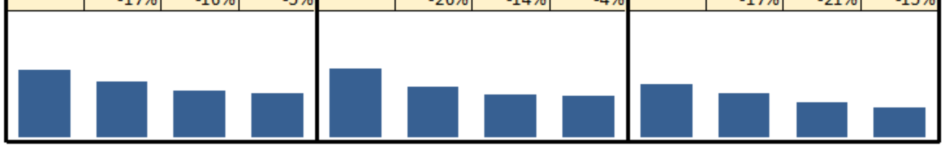
The ASTM F2961-22 Test Method requires that a test subject must be able to torque 4.5 to conduct the measurement for %BHCV. Therefore, we removed those test subjects from our data and recalculated the Coefficient of Variation as shown in Table 4.8. Removing those study participants who could not torque at least 4.5 resulted in better results for females but worse results for males.

Table 4.8: Coefficients of Variation for Bare Hand, Leather, & HPT gloves; implementing minimum requirement of 4.5 ability

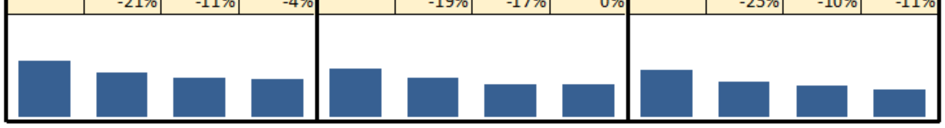
Sex	Bare Hand				Leather				HPT			
Female	CVBH2	CVBH3	CVBH4	CVBH5	CVLTH2	CVLTH3	CVLTH4	CVLTH5	CVHPT2	CVHPT3	CVHPT4	CVHPT5
N	31	31	31	31	31	31	31	31	31	31	31	31
Std. Deviation	0.054	0.044	0.053	0.051	0.033	0.035	0.029	0.031	0.060	0.045	0.046	0.043
Mean	0.060	0.065	0.082	0.081	0.059	0.062	0.065	0.065	0.078	0.088	0.086	0.088
CoV	0.899	0.674	0.645	0.630	0.561	0.564	0.447	0.479	0.767	0.512	0.538	0.493
%change		-25%	-4%	-2%		1%	-21%	7%		-33%	5%	-8%



Male	Bare Hand				Leather				HPT			
N	40	40	40	40	40	40	40	40	40	40	40	40
Std. Deviation	0.043	0.04474	0.050	0.04967	0.062	0.04513	0.040	0.03908	0.046	0.04383	0.035	0.02846
Mean	0.052	0.06572	0.088	0.09169	0.074	0.07354	0.076	0.07761	0.071	0.08099	0.081	0.07821
CoV	0.822	0.681	0.572	0.542	0.835	0.614	0.526	0.504	0.650	0.541	0.428	0.364
%change		-17%	-16%	-5%		-26%	-14%	-4%		-17%	-21%	-15%



N	71	71	71	71	71	71	71	71	71	71	71	71
Std. Deviation	0.040	0.037	0.043	0.042	0.041	0.034	0.029	0.030	0.043	0.037	0.033	0.029
Mean	0.046	0.055	0.071	0.073	0.056	0.057	0.059	0.060	0.062	0.070	0.070	0.069
CoV	0.859	0.678	0.603	0.578	0.730	0.594	0.494	0.494	0.704	0.528	0.477	0.424
%change		-21%	-11%	-4%		-19%	-17%	0%		-25%	-10%	-11%

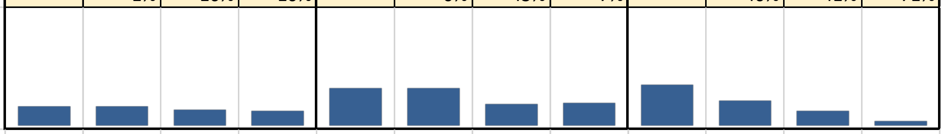
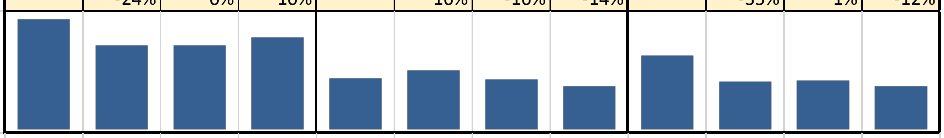
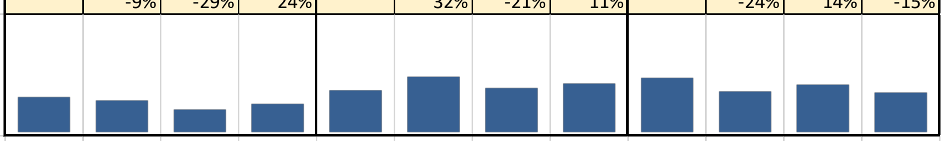


Coding explanation: CV = Coefficient of Variation | BH = Bare Hand | LTH = Leather Glove | HPT = HPT Glove | 2=after 2 iterations | 3=after 3 iterations | 4=after 4 iterations | 5=after 5 iterations

4.6.1 Analysis by hand size

We also investigated whether hand size played a factor in the CV results and consistency. In the following tables, 4.9, 4.10, and 4.11, we separated hand size by females, males, and total test participants respectively. Separated by sex, females of all hand sizes did not meet our definition of consistency in any case. Males of hand size nine met the definition of consistency for Bare Hand, leather glove, and HPT glove. However, when separated by hand size, the test population of some sizes was simply too few to be significant. When combined, size nine appears to be the most consistent across all situations.

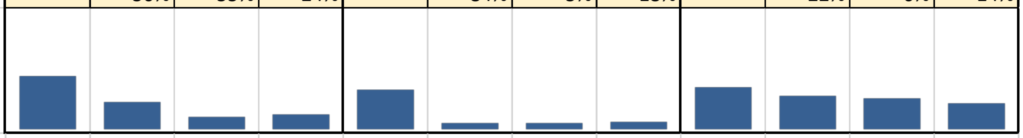
Table 4.9: Coefficient of Variation - Female by Hand Size

Female	GSizeEU#	CVBH2	CVBH3	CVBH4	CVBH5	CVLTH2	CVLTH3	CVLTH4	CVLTH5	CVHPT2	CVHPT3	CVHPT4	CVHPT5
Female	**7**												
N		3	3	3	3	3	3	3	3	3	3	3	3
Std. Deviation		0.019	0.017	0.016	0.015	0.061	0.047	0.028	0.030	0.028	0.030	0.018	0.005
Mean		0.073	0.063	0.072	0.073	0.116	0.090	0.095	0.094	0.049	0.085	0.085	0.085
CoV		0.267	0.265	0.223	0.201	0.524	0.522	0.297	0.317	0.582	0.349	0.208	0.060
%change			-1%	-16%	-10%		0%	-43%	7%		-40%	-41%	-71%
													
Female	**8**												
N		33	33	33	33	33	33	33	33	33	33	33	33
Std. Deviation		0.128	0.107	0.132	0.144	0.051	0.067	0.056	0.049	0.103	0.070	0.069	0.064
Mean		0.083	0.090	0.112	0.111	0.071	0.080	0.080	0.081	0.100	0.104	0.101	0.106
CoV		1.547	1.177	1.177	1.291	0.717	0.829	0.699	0.602	1.038	0.678	0.686	0.606
%change			-24%	0%	10%		16%	-16%	-14%		-35%	1%	-12%
													
Female	**9**												
		7	7	7	7	7	7	7	7	7	7	7	7
		0.023	0.022	0.019	0.027	0.042	0.055	0.043	0.045	0.056	0.057	0.069	0.057
		0.046	0.048	0.059	0.067	0.071	0.069	0.069	0.065	0.073	0.097	0.104	0.101
		0.499	0.455	0.322	0.399	0.596	0.787	0.625	0.695	0.771	0.584	0.664	0.563
			-9%	-29%	24%		32%	-21%	11%		-24%	14%	-15%
													

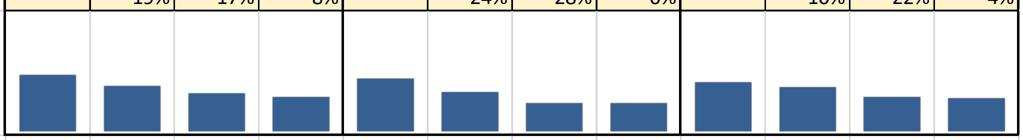
Coding explanation: GSizeEU# = European Glove Size Number | CV = Coefficient of Variation | BH = Bare Hand | LTH = Leather Glove | HPT = HPT Glove | 2=after 2 iterations | 3=after 3 iterations | 4=after 4 iterations | 5=after 5 iterations

Table 4.10: Coefficient of Variation: Male by hand size

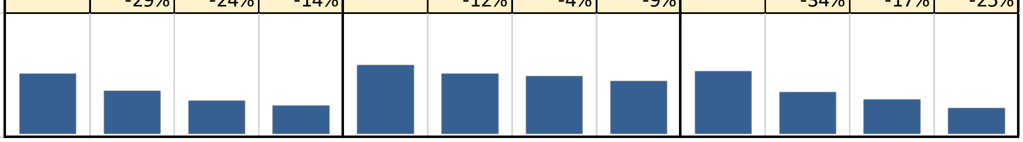
	GSizeEU#	CVBH2	CVBH3	CVBH4	CVBH5	CVLTH2	CVLTH3	CVLTH4	CVLTH5	CVHPT2	CVHPT3	CVHPT4	CVHPT5
Male	8												
N		3	3	3	3	3	3	3	3	3	3	3	3
Std. Deviation		0.027	0.021	0.013	0.016	0.016	0.008	0.008	0.009	0.039	0.035	0.032	0.026
Mean		0.037	0.056	0.081	0.075	0.029	0.087	0.093	0.088	0.067	0.076	0.075	0.071
CoV		0.725	0.366	0.166	0.206	0.542	0.089	0.085	0.100	0.582	0.454	0.426	0.365
%change			-50%	-55%	24%		-84%	-5%	18%		-22%	-6%	-14%



	GSizeEU#	CVBH2	CVBH3	CVBH4	CVBH5	CVLTH2	CVLTH3	CVLTH4	CVLTH5	CVHPT2	CVHPT3	CVHPT4	CVHPT5
Male	9												
N		27	27	27	27	27	27	27	27	27	27	27	27
Std. Deviation		0.044	0.048	0.053	0.052	0.060	0.041	0.031	0.032	0.061	0.058	0.044	0.039
Mean		0.057	0.076	0.102	0.107	0.082	0.075	0.079	0.081	0.089	0.093	0.091	0.086
CoV		0.782	0.633	0.524	0.482	0.726	0.552	0.400	0.400	0.681	0.616	0.479	0.458
%change			-19%	-17%	-8%		-24%	-28%	0%		-10%	-22%	-4%

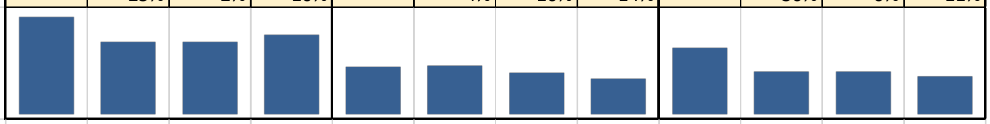
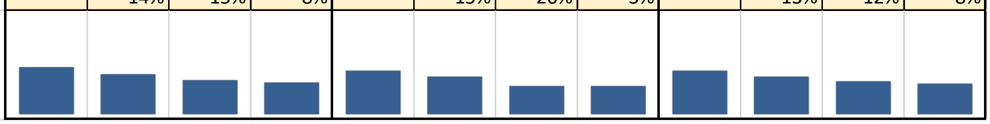


	GSizeEU#	CVBH2	CVBH3	CVBH4	CVBH5	CVLTH2	CVLTH3	CVLTH4	CVLTH5	CVHPT2	CVHPT3	CVHPT4	CVHPT5
Male	10												
N		12	12	12	12	12	12	12	12	12	12	12	12
Std. Deviation		0.036	0.026	0.026	0.023	0.063	0.054	0.054	0.052	0.050	0.043	0.037	0.028
Mean		0.043	0.043	0.057	0.058	0.066	0.064	0.067	0.071	0.058	0.076	0.077	0.077
CoV		0.842	0.598	0.452	0.389	0.953	0.837	0.807	0.732	0.872	0.573	0.477	0.360
%change			-29%	-24%	-14%		-12%	-4%	-9%		-34%	-17%	-25%



Coding explanation: GSizeEU# = European Glove Size Number | CV = Coefficient of Variation | BH = Bare Hand | LTH = Leather Glove | HPT = HPT Glove | 2=after 2 iterations | 3=after 3 iterations | 4=after 4 iterations | 5=after 5 iterations

Table 4.11: Coefficient of Variation: By hand size only

Sex		GSizeEU#	CVBH2	CVBH3	CVBH4	CVBH5	CVLTH2	CVLTH3	CVLTH4	CVLTH5	CVHPT2	CVHPT3	CVHPT4	CVHPT5
	Total	**8**												
	N		36	36	36	36	36	36	36	36	36	36	36	36
	Std. Deviation		0.121	0.100	0.123	0.134	0.050	0.062	0.053	0.046	0.100	0.067	0.066	0.061
	Mean		0.079	0.088	0.110	0.108	0.067	0.081	0.081	0.082	0.097	0.101	0.098	0.103
	CoV		1.526	1.144	1.126	1.241	0.742	0.769	0.646	0.557	1.036	0.663	0.667	0.593
	%change			-25%	-2%	10%		4%	-16%	-14%		-36%	0%	-11%
														
	Total	**9**												
			34	34	34	34	34	34	34	34	34	34	34	34
			0.041	0.045	0.051	0.050	0.057	0.044	0.034	0.036	0.060	0.057	0.050	0.044
			0.054	0.070	0.093	0.099	0.080	0.074	0.077	0.078	0.086	0.094	0.094	0.089
			0.753	0.647	0.551	0.509	0.710	0.603	0.449	0.463	0.701	0.609	0.535	0.494
				-14%	-15%	-8%		-15%	-26%	3%		-13%	-12%	-8%
														

Coding explanation: GSizeEU# = European Glove Size Number | CV = Coefficient of Variation | BH = Bare Hand | LTH = Leather Glove | HPT = HPT Glove | 2=after 2 iterations | 3=after 3 iterations | 4=after 4 iterations | 5=after 5 iterations

CHAPTER 5: GRIP STRENGTH VERSUS GRIPPING PERFORMANCE OF PROTECTIVE GLOVES

5.1 Abstract

Using ASTM F2961-22 *Test Method for Characterizing Gripping Performance of Gloves Using a Torque Meter*, we investigated the role of grip strength to the torquing ability of the test participants. One glove used was a pigskin leather glove, and the other was a lined knit glove with a synthetic coating over the palm and anterior phalanges. Test participants torqued a 1.625” diameter acrylic rod with their bare hand, with the leather glove and with the knit glove five times each. The ratio of gloved hand to bare hand is called the Percent Bare Hand Control Value (%BHCV). The results showed that the pigskin leather glove had a %BHCV below 100%, meaning that it had less grip than bare skin. The lined, knit glove had a %BHCV greater than 100%, meaning that it had more grip than bare skin. Then, we used a pressure-mapping glove under each test glove to determine maximum grip strength used while torquing the rod. Our results showed that less grip strength was required with the glove that had greater gripping performance.

5.2 Introduction

ASTM F2961-22 *Test Method for Characterizing Gripping Performance of Gloves Using a Torque Meter* is one of two recognized test methods to characterize the gripping performance of protective gloves (ASTM International, 2022b). The other is a rope pull method used by the National Fire Protection Association (NFPA) (National Fire Protection Association, 2015). Along with their own test method, the NFPA has incorporated ASTM F2961 into their specification for turn-out gear in several of their standards (National Fire Protection Association, 2015, 2016a, 2016b, 2018a, 2018b, 2018c, 2018d, 2020a, 2020b). ASTM summarizes the F2961 test method as: "The maximum torque applied to a vertically oriented cylindrical rod is measured without gloves and then later while wearing gloves. The bare hand maximum torque is compared to the gloved hand maximum torque in terms of a percentage. This percentage is useful in determining if a glove enhances or decreases an individual's ability to grip a hard object." (ASTM International, 2022b) This percentage is called Percent Bare Hand Control Value (%BHCV) and is calculated as follows:

$$\frac{T_G}{T_B} \times 100 = \%BHCV$$

Equation 5.1: Bare Hand Control Value

where:

%BHCV = percentage of bare-handed control value,

T_G = average maximum torque applied with gloved hand, and

T_B = average maximum torque applied with bare hand.

Values higher than 100 %BHCV indicate that gloves tested enhance the wearer's ability to grip a solid object, while values lower than 100 % decrease the wearer's ability to grip a solid object (ASTM International, 2022b).

In this study, we investigated the role of grip strength to achieve maximum torque while performing this test method. This study will help determine whether greater grip strength was required to attain greater %BHCV of these two glove samples, and whether the torque achieved is impacted by hand adherence, i.e., adherence of the glove to the skin or, simply put, the movement of the hand inside of the glove. If greater grip strength is needed, muscle fatigue may become a factor when wearing the glove.

Although glove adherence to a grasped object, and hand adherence to a glove has been examined; one study used grasping and not torquing (Gauvin *et al.*, 2008), and another was a measurement of hand supination torque rather than the flexion-type torque used in this test method (Axelsson *et al.*, 2018). Studies acknowledged that glove adherence using flexion torque was measurable but could only use perception as the measurement for hand adherence to a glove (Chen *et al.*, 1989; Gauvin *et al.*, 2008). However, perception of hand adherence while simultaneously torquing a solid object (i.e., glove adherence) was difficult and inconsistent.

Several studies have examined the effects of gloves to maximum volitional contraction (MVC), time needed to reach MVC (T_{MVC}), total force generation (TFG), and maximum endurance time (MET). These studies have used grip strength as their predominant measurement. They typically found that the glove thickness negatively effects MVC (Chang & Shih, 2007; Fleming *et al.*, 1997; Kovacs *et al.*, 2002; Shih, 2007). Some postulate that as compression forces increase during the grip, some work is stored as elastic energy in the creases of the glove (Tsaousidis & Freivalds, 1998), or put another way, the reduction in grip strength when wearing gloves is likely because of the mechanics of the glove during the gripping action; that is, the glove absorbs some of the hand energy (Wimer *et al.*, 2010).

Previous studies typically are task-specific or determined hand-hold orientation or other ergonomic considerations (Imrhan & Farahmand, 1999; Young *et al.*, 2012). This study is not measuring a person's maximum grip strength but rather the amount of grip strength, in pounds, needed to apply maximum torque measured in Newton meters. In fact, as a person puts their wrist into flexion, grip strength decreases (Kattel *et al.*, 1996; Seo *et al.*, 2008). Therefore, the comparison to %BHCV and grip strength in this study is only to ensure that hand adherence inside the glove has no or limited effect on the characterization of the glove grip.

5.3 Materials and Methods

This study was approved by the institution's Institutional Review Board (number: 185-21-EP).

5.3.1 Study design

This project used a sequence of experimental studies to validate and enhance the ASTM F2961 Test Method. In this final part, called "Grip Performance vs. Grip Strength" (See Figure 5.1), 32 study participants were asked to torque a 1.625 in. diameter acrylic rod with their bare, self-declared dominant hand. In addition, those participants donned two disparate glove types and torqued the 1.625" diameter acrylic rod while wearing each type of glove. One was a pigskin leather glove, Orr Safety Corporation (Louisville, KY) Leather Drivers Glove, model ORRFB570 (referred to as "Leather Glove" in this study). The other was a lined, knit glove with a synthetic coating over the palm and anterior phalanges, MCR Safety (Collierville, TN) Ninja® Ice model N9690 dipped in a proprietary synthetic dip called HPT™ (referred to as "HPT Glove" in this study). Lastly, we outfitted that same hand with a Tekscan™ Grip™ System (Tekscan, Inc., Boston, MA) [See Appendix J for manufacturer's information] which is a tactile grip force and pressure measurement device (Figure 5.2). The Tekscan™ sensors were adhered to a thin, cotton lisle inspection glove (model ORRFA710 procured from Orr Safety Corporation (Louisville, KY)) using Pellon brand, Style ST-920 "EZ

Figure 5.1: Sequential process flow of experimentally designed research study. Step Three.

Fix Tape", clear two-sided pressure sensitive adhesive fabric tape (glove and attached sensors are referred to as "Tekscan™ glove" in this study). The test glove was carefully donned over the Tekscan™ glove, calibrated, and the test participant was asked to torque the acrylic rod in the same manner as before. Sequence of leather glove, HPT glove, and bare hand was randomized but the test participant completed the five iterations for each situation before going to the next. We recorded the maximum torque achieved at each torquing iteration. In addition, when using a Tekscan™ glove, we recorded the 5-second iterations using the software for the system (GRIP Research 6.85). After applying the calibration to the recording, we determined the maximum grip strength used during the torque, in pounds. We compared the maximum torque achieved for each iteration to the maximum grip strength used during the same iteration. Then, we determined if grip strength was a contributing factor to the torque measurements and, thus, for the %BHCV results for the Leather and HPT gloves.

5.3.2 Study participants

Study participants were recruited using an 8 ½" x 11" flyer that could be printed and posted or sent electronically. Study participants in the Omaha, Nebraska, area were the prime targets since the project required in-person testing. Most study participants were recruited through a local safety professional organization, internet advertising, and through personal contacts. When a person was interested in participating, the person was directed to an on-line calendar program called "Calendly" (https://calendly.com/) where the person could schedule their testing appointment. To be included in the study, participants had to be between 19 and 65 years old, able to understand English, and not have medical conditions (arthritis, tendonitis, surgery, etc.) that might prohibit them from standing or using maximum grip strength and hand torque for 20 repetitions within an hour.

Figure 5.2: Photos of Tekscan™ glove creation and use

5.3.3 On-boarding

After the study participant signed the Informed Consent, they completed the demographic portion of the data collection sheet. These data points were: 1) age at last birthday, 2) sex at birth, and 3) declared dominant hand. The study proctor then measured the study participant's hand circumference and Digit3 Link Length using a vinyl-coated cloth tape measure. The measurement technique followed the *Hand Anthropometry of U.S. Army Personnel* (Greiner, 1991). Measurements were recorded in both inches and centimeters. Numeric hand size was determined based on hand circumference as per the European Standard, DIN EN 420 - Protective gloves – General requirements and test methods. (Deutsches Institut für Normung e. V., 2010b) . The United States has no comparable standard; therefore, the European standard was utilized. The European standard uses the hand circumference, in mm, to determine hand size. The "hand size" is a conventional designation of hand size corresponding to the hand circumference expressed in inches. (European Committee for Standardization, 2010) Hand size for this study was used to ensure the proper glove size for each test participant. The European sizing chart was used for male and female study participants. The randomized sequence of testing was also written on the data collection sheet to inform the test participant and the test proctor.

For our study, we generalized the ages into groups to compare with previous studies. Since protective gloves are typically used in an industrial environment; we studied working-age (ages 19 - 65) adults. We made three even groups and labeled them "early career" (ages 19 – 35), "mid-career" (ages 36 – 50), and "late career" (ages 51 – 65) for our study. This made it easier to ensure we had an appropriate number of test participants of working-age spectrum.

5.3.4 Testing protocol

All gloves were conditioned at a temperature of 21 ± 3°C (70 ± 5°F) and a relative humidity of 65 ± 5% for at least 24 hours. This was accomplished by hanging all pairs of test gloves inside a climate-controlled Environmental Testing Chamber. The chamber provided a thermal environment where the temperature was consistently within ±0.1 °F while also controlling humidity well within the parameters of the test method. The chamber had a steam humidification system and used a refrigeration system to remove humidity and provide cooling, with heating provided by electrical heaters. All test subjects conducted their torque iterations while inside the chamber.

Figure 5.3: Calibration of Tekscan™ glove

Calibration of the Tekscan™ - Test Glove combination was done before and after each set of iterations for each test participant and for each test glove. This was done using the "point calibration" method described by the Tekscan™ literature. The test subject donned the Tekscan™ glove, then donned the test glove over the Tekscan™ glove. While connected to the datalogger, the participant would compress a calibrated Jamar® Hydraulic Grip Strength Dynamometer (Sammons Preston, Bolingbrook, IL) to a defined pound amount based on their approximate maximum capability. The calibration amounts were typically between 25% and 75% of their maximum capability, and then rounded to the next lowest 10-pound increment on the Jamar dynamometer. For example, if the person's approximate capability was 42 pounds, we would calibrate at 10 pounds and 30 pounds. The test participant would squeeze the dynamometer until it read 10 pounds. That point was recorded. Then, the participant would squeeze the dynamometer to 30 pounds. That point was recorded. Then, the calibration arc on the Tekscan™ was observed. The straighter the arc, the better the calibration. If the arc was outside the parameters of the programming, the calibration was attempted again. In most cases, the calibration arc was acceptable the first time (See Figure 5.3 for photograph of setup). This calibration sequence is required to convert the Tekscan™ pressure to a usable dimension, in this case, pounds. We utilized two different Grip™ system dataloggers to increase throughput of test participants, a tethered (2-Port VersaTek Hub) and an untethered model (Datalogger VersaTek Unit). Each had a scan rate of 750 Hertz [see Appendix K for instructions].

Proctors were given written instructions on how to conduct the testing. The test proctor explained the process to the study participant. We erected four identical testing stations to be able to test four subjects at one time. Each station had a torque meter equipped with a 1.625" acrylic rod diameter size. Torque meters were Param® NJY-40 Digital Torque Testers purchased from LabThink® (Boston, MA). Torque Testers were calibrated according to manufacturer's specifications to 20 Newton-meters (N m). Calibration was conducted when meters were set in place and prior to removal. The meters and acrylic rods were manufactured by LabThink® and (Boston, MA). The sequence with which each study participant completed the testing was randomized using random.org on-line program. Study participants used their declared dominant hand to torque the rod as hard as they could for five seconds. Then, they rested for one minute. This torque-rest period was called one iteration. Each study participant conducted five iterations then rested for five minutes before going to the next sequence item. Therefore, a person would torque five iterations of the first sequence item (i.e. bare hand, Leather glove, HPT glove, Leather glove with Tekscan™ glove, and HPT glove with Tekscan™ glove), rest for five minutes, then torque five iterations of the next sequence item, rest for five minutes, and so on until all five situations were completed. When conducting the sequence items that included the Tekscan™ glove, additional time was needed for setup, so the test participant had more than five minutes of rest at those points. We recorded the maximum torque achieved at each torquing iteration. The Tekscan™ equipment data logged the five seconds, and we recorded the maximum grip strength used during each iteration. This work-rest method was consistent with the ASTM method and with accepted biomechanical testing (Chaffin *et al.*, 2006).

Study participants were instructed on the proper body position for the testing prior to the start of the iterations. Study participants were instructed to stand such that they grab the acrylic rod with the elbow bent at a right angle and the upper arm against the side of the body (See Figure 5.4 for example). When needed, proctors adjusted the height of the test apparatus to provide the proper body and arm orientation. Proctors were not allowed to encourage the study participant at any time during the testing; their effort must be their natural maximum effort. To minimize bias, the study participant was not able to observe the reading from the torque meter or learn of the applied torque until all iterations were completed. In addition, except when wearing the Tekscan™ glove, study participants were instructed to

Figure 5.4: Test Participant showing proper posture

remove the test glove between iterations to help control for temperature fluctuations caused by body heat. Each study participant was given a new pair of each style of glove.

When the study participant completed all iterations for the bare and gloved hand, the end time was recorded. Start-Stop times were recorded to ensure no wide variations of temperature and humidity took place during a person's testing in the event of a failure of the environmental chamber. That did not occur and there were no variations of temperature or humidity outside the parameters of the test method.

5.3.5 Data analysis

Ages of study participants were grouped into early, mid, and late career groups. Early-career included study participants between the ages of 19 and 35. Mid-career was defined as study participants between the ages of 36 and 50, and late career included study participants between the ages of 51 and 65. This was to ensure that we had a good cross-section of working aged adults. However, in the previous two studies described in chapters three and four, we found that age was not a factor in a person's ability to torque the acrylic rod.

Statistical analyses were carried out with IBM SPSS Statistics 28.0.0 (IBM Corp. Released 2021. IBM SPSS Statistics for Windows, Version 28.0.0. Armonk, NY: IBM Corp). Paired samples t-tests, descriptive characteristics, and analyses of the means with ANOVA were utilized in the analysis of the data. An alpha value of 0.05 was considered statistically significant.

5.4 Results and Discussion

The demographics of study participants are provided in Table 5.1. Seventeen males (53.1%) and 15 females (46.9%) participated in this study.

Table 5.1. Descriptive characteristics of participants

Variables	N	%	$\bar{x}$	σ
Gender				
Female	15	46.9		
Male	17	53.1		
Career Group (age range)				
Early Career (19 – 35)	11	34.4	29.5	±5.0
Mid-Career (36 – 50)	11	34.4	42.2	±5.3
Late Career (51 – 65)	10	31.3	59.3	±5.4
Hand Size (Based on Hand Circumference (cm))				
8	13	40.6		
9	14	43.8		
10	5	15.6		
Hand Dominance				
Right Hand Dominant	31	96.9		
Left Hand Dominant	1	3.1		

5.4.1 Mean Maximum Torque based on Sequence

To ensure that the sequence of torquing iterations had no effect on results, we conducted a comparison of the means of each sequence. Results showed no significant difference in the mean maximum torque for bare hand sequence number ($p = 0.435$), leather glove sequence number ($p = 0.466$), and HPT glove number ($p = 0.398$).

5.4.2 Torque ability with and without Tekscan™ glove

We were concerned that the Tekscan™ glove might impact the test participants' ability to torque the acrylic rod. Results in Table 5.2 show the Mean Maximum Torque with and without the Tekscan™ glove for both the HPT glove and the Leather glove. The mean maximum torques were strongly correlated for both the Leather glove and HPT glove for males (r^2=0.897, p<0.001; r^2=0.779, p<0.001; respectively) and females (r^2=0.851, p<0.001; r^2=0.889, p<0.001; respectively). Therefore, total mean maximum torques were strongly correlated for both types of gloves (Leather: r^2=0.929, p<0.001; HPT: r^2=0.870, p<0.001). It also showed no significant difference between mean maximum torques when conducted with and without the Tekscan™ glove.

Table 5.2: Summary of Mean Maximum Torque with and without Tekscan™ under-glove by Sex

	Male	**Female**	**Total**
n	17	15	32
Mean Maximum Torque Leather Glove (N m)	5.908	4.306	5.157
Mean Maximum Torque Leather Glove w/ Tekscan™ under-glove (N m)	6.120	4.154	5.199
p-value (Leather Glove)	(p = 0.183)	(p = 0.233)	(p = 0.689)
Mean Maximum Torque HPT Glove (N m)	7.793	5.714	6.818
Mean Maximum Torque HPT Glove w/ Tekscan™ under-glove (N m)	7.697	5.764	6.791
p-value (HPT Glove)	(p = 0.734)	(p = 0.764)	(p = 0.866)

5.4.3 Mean %BHCV versus Mean Maximum Grip Strength

The measurement of glove grip is done using percent bare hand control value. Table 5.3 shows that the HPT glove had better grip than the Leather glove when not using the Tekscan™ glove ($p < 0.001$) and when using the Tekscan™ glove ($p < 0.001$). It also shows that it took more grip strength from the participants to achieve the %BHCV of the leather glove than of the HPT glove ($p < 0.001$). The mean %BHCV for the HPT glove were also statistically the same ($p < 0.001$). This indicates that wearing a glove that has a high %BHCV may reduce required grip strength for performing work, and, therefore, may be a consideration when selecting appropriate protective gloves.

Table 5.3: Mean %BHCV versus Mean Grip Strength

	Leather	**HPT**
n	32	32
Mean %BHCV without Tekscan™ glove	87.1 (s = 19.3; SE = 3.4)	114.6 (s = 20.2; SE = 3.6)
Mean %BHCV with Tekscan™ glove	87.0 (s = 20.4; SE = 3.6)	113.8 (s = 23.0; SE = 4.1)
Mean Grip Strength (pounds)	31.5 (s = 13.8; SE = 2.4)	25.6 (s = 9.7; SE = 1.7)

s = standard deviation SE = Standard Error of the mean

5.4.4 Grip Strength and Hand Adherence discussion

The HPT glove was a lined, knit glove, and the Leather glove was not lined, therefore the HPT glove was thicker than the Leather glove. The HPT glove had better glove grip as measured by the percent bare hand control value, but test subjects appeared to use less grip strength. The measurement device for grip strength was place beneath the test glove but over a cotton lisle glove, so there were two places where hand slippage could have occurred, between the hand and the lisle glove and between the Tekscan™ sensors and the test glove. Had slippage occurred inside the test glove, we would have expected the grip strength to increase to compensate for the slippage. If the Tekscan™ glove was causing slippage, we would have expected to see different %BHCV between the with and without Tekscan™, which we did not. If the hand – lisle glove interface was causing slippage, we would have seen similar amounts of slippage between the Leather glove and HPT glove.

Likewise, if the glove adherence to the acrylic rod slipped, we would also expect to see higher grip strength to compensate for that slippage. In addition, we would see the slippage in the Tekscan™ pressure mapping. There was very little indication that this was occurring in most cases.

We calibrated the Tekscan™ to the glove; so, for example, the grip strength of the HPT glove of 20 pounds would equal the grip strength of 20 pounds of the Leather glove. To prove that we switched the calibration files; that is, we used the HPT glove calibration file on the Leather glove results and vice versa. The calibration file is a computer file that contains each individual's data when they calibrated the Tekscan™ as described in paragraph 5.3.4. The mean grip strength between the correct and cross-calibration for Leather and for HPT were still highly correlated ($r^2 = 0.739$; $p<0.001$ and $r^2 = 0.669$; $p<0.001$; respectively).

We would expect high correlation since we are using the same data but applying a different calibration. Therefore, we looked at the paired differences of the mean grip strength. Table 5.4 shows the results of cross calibrating the HPT glove with the Leather glove and vice versa. The difference in mean grip strength between the correctly calibrated and cross-calibrated results are statistically insignificant, indicating that glove thickness in this case was likely not a confounder.

Table 5.4: %BHCV versus Grip Strength using cross-calibration

	Leather	**HPT**
n	32	32
Mean %BHCV with Tekscan™ glove	87.0 (s = 20.4; SE = 3.6)	113.8 (s = 23.0; SE = 4.1)
Mean Grip Strength using correct calibration (pounds)	31.5 (s = 13.8; SE = 2.4)	25.6 (s = 9.7; SE = 1.7)
Mean Grip Strength using cross-calibration (pounds)	34.7 (s = 20.1; SE = 3.6)	26.1 (s = 12.2; SE = 2.2)
Grip strength p-value (correct to cross-calibration)	p = 0.181	p = 0.805

s = standard deviation SE = Standard Error of the mean

5.5 Conclusions

This study was the final step in fully validating and enhancing the ASTM F2961-22 *Test Method for Characterizing Gripping Performance of Gloves Using a Torque Meter*. We found that a glove with higher %BHCV reduced the grip strength needed to achieve maximum torque. This is important in that if greater grip strength is needed to do work while wearing a glove (such as climbing a ladder or getting on or off equipment), a glove with better %BHCV should be considered.

The current test method only requires the measurement of gloved hand torque versus bare hand torque. It does not require the measurement of grip strength while conducting the torque iterations. We believe the results of this study verify that grip strength measurements are not needed as part of the ASTM test method. This study showed that lower grip strength is needed for a glove with higher %BHCV and that lower %BHCV-rated gloves require higher grip strength.

Future studies should consider glove grip characteristics when gloves are wet with water or wet with oil. The results of which can then be used to inform consumers on the characteristics of glove grip before purchasing a protective glove. This would be a benefit to those occupations that involve exposure to wet or damp environments, such as employees in the fishing industry or fire fighters; and occupations that involve exposure to oily or greasy environments, such as employees in the automotive repair or oil industries.

CHAPTER 6: CONCLUSION

Protective gloves are a major component of PPE and are a necessity throughout the world and in most industries. There are many attributes of protective gloves that employers and PPE vendors need to consider when selecting appropriate gloves for a task. Each task should be evaluated for hazard exposures and the Hierarchy of Controls should be used to mitigate those hazards. When more reliable mitigation techniques are found to be untenable, protective gloves are the last line of protection in those tasks.

Employers and vendors can refer to a myriad of consensus standards, test methods, and regulations to help determine the right glove for the job. These documents describe the requirements and best practices that should be considered in glove selection. Our research focused on one attribute: glove grip characterization. Currently, there is only one international test method recognized by one standard-making organization in a very limited application. But, because that test method used a very small number of test subjects in its development, our research project's aim was to validate and enhance the test method.

We conducted a three-step research process using a larger test population than the original study to ensure statistical significance could be reached. First, we conducted the method optimization step that ensured the basics of the test method were correct. This included ensuring the rod size was correct regardless of a person’s sex, age, and hand size. We also started the investigation into the number of required iterations.

Then, in step two, we used the current test method to determine the %BHCV on two disparate gloves. We determined that %BHCV was not significantly different by sex, by age, by hand size, or by differences in torquing ability. We also determined the number of test subjects and number of torquing iterations needed to achieve the most consistent results.

The final step was to investigate how grip strength effected %BHCV and vice versa. If a glove has great grip characterization, but it causes a person to exert more grip strength, it may not be beneficial.

6.1 Study Findings

Question 1: *Does the diameter size of the acrylic rods produce differing average maximum torque values based on hand size?*

Finding: We thought that persons with smaller hands might be able to torque smaller diameter rods better. That was not the case. As the rod size increased, the torque values increased for males and females. However, the 1.625 in. rod size, as mandated by the ASTM F2961 Test Method, gave the most consistent results between males and females, which is beneficial for a test method.

Question 2: *How many iterations of torquing the acrylic rod is adequate to obtain consistent, average maximum torque results?* Current ASTM F2961-22 Test Method dictates five iterations.

Finding: When it came to just a bare hand, consistent results were achieved after only four iterations. However, when comparing gloved hands to bare hands, five iterations were required.

Question 3: *How many iterations are needed for most test participants to achieve the highest torque?*

Finding: The highest torque value was achieved by 50% of the test participants on or before their 3rd iteration, and by 75% of the test participants on or before their 4th iteration.

Question 4: *Are three test participants adequate to give consistent %BHCV results?*

Finding: After looking at the intrapersonal coefficient of variation, we investigated the Variability Estimate of groups of test subjects. The data indicate that using four randomly selected test subjects result in a tighter variability in the %BHCV than three or five people. We only examined groups up to five people because this is a test method and there is a diminishing return when requiring more test subjects.

Question 5: *How do the torquing abilities of males and females differ?*

Finding: The bare-hand torque values for males using the 1.625 in. acrylic rod averaged 6.995 N m versus an average of 4.520 N m for females. This difference was significant and expected. However, when calculating %BHCV, this difference in torquing ability was not statistically significant.

Question 6: *How does torquing ability relate to age?*

Finding: We found no evidence that age was a factor in the mean maximum torque achieved by males or females. This was true of Bare Hand, Leather gloved hand, and donned HPT glove. However, this research was conducted using only those age 19 through 65; that is, working-age adults.

Question 7: *Does %BHCV differ significantly between males and females?*

Finding: Although females had a higher %BHCV than males for the two types of gloves studied, the difference was not significant, and showed no correlation due to sex.

Question 8: *Does %BHCV differ significantly based on age?*

Finding: There was no significant difference in %BHCV between age groups. One caveat is that all our test participants were working-age adults; that is 19 through 65 years of age.

Question 9: *Is it necessary to require test subjects to torque a minimum of 4.5 ?*

Finding: In our study, we found this requirement to be unnecessary and it may negatively impact females by eliminating them from the test participant pool. Percent Bare Hand Control Values were not significantly different with those with lower torquing abilities. When we removed the data for participants that could not torque at least 4.5 ; the consistency remained similar. This information could help laboratories recruit test participants.

Question 10: *Must a person grip harder in certain types of gloves to achieve maximum torque?*

Finding: In our study, the HPT glove had better %BHCV than the Leather glove. However, our data also shows that it took more grip strength from the participants to achieve the %BHCV of the leather glove than of the HPT glove.

Question 11: *Does a glove with high %BHCV require greater or lesser grip strength while torquing the acrylic rod?*

Finding: Using the information from the last question, indications are that wearing a glove that has a high %BHCV may reduce required grip strength for performing work, and, therefore, may be a consideration when selecting appropriate protective gloves.

6.2 Significance of study findings

This study validated the ASTM F2961-22 *Test Method for Characterizing Gripping Performance of Gloves Using a Torque Meter*. We believe it also provided areas for improvement of the test method, such as removing the requirement for 4.5 . Because we could calculate statistical significance, the test method could get better acceptance in the industry and be adopted by more standards development organizations.

We found that a glove with higher %BHCV reduced the grip strength needed to achieve maximum torque. This is important in that if greater grip strength is needed to do work while wearing a glove (such as climbing a ladder or getting on or off equipment), a glove with better %BHCV should be considered.

6.3 Strengths and limitations

One of the greatest strengths of this study as compared to earlier studies is the number of test participants for each step of the research process. However, we did not record detailed participant demographics to see if our test population could be generalized to the greater population. This study was conducted in Omaha, Nebraska, and test participants were mostly students at the University or nearby residents. We had ethnic diversity in our test sample, but we cannot say that our results can be generalized to the general public in that regard. Had we ensured that our test sample reflected the demographics of the country, we might have had somewhat different torque results. However, we believe that the %BHCV results would not have changed since we determined that hand size, age, sex, and torquing ability had no influence on those results.

The first limitation of this study was that we used only two styles of protective gloves. Although the glove styles were disparate in construction and gripping characteristics, conducting this test on more types and styles of gloves would give greater insight on how %BHCV and grip strength were correlated. Now that we have validated the test method, this can now be done and further study using a grip strength measuring apparatus like the Tekscan™ could provide more insight.

A second limitation was that we did not have a datalogging torque meter. Merging the torque data and grip strength data on a graphical depiction of elapsed time could have answered more questions. It would be interesting to see how the grip strength changes as the torque value changed. It could give insight as to what happens during the torquing event, such as: can we see on the graphical depictions when a person compensates for hand slippage; or does a person's effort fluctuate during the five seconds. Although understanding this may not have changed any results of our study, it would be interesting to understand these phenomena.

The third limitation is the calibrating the Tekscan™ glove using a single plain, handle dynamometer may not be the best way to do so. Using this type of dynamometer puts greater point pressure where the fingers wrap around the handle. Therefore, the Tekscan™ instrumentation would show peaks in some sensors and nothing in other sensors whereas the actual torquing of the cylindrical acrylic rod might more fully spread the pressure to more parts of the hand. Perhaps the use of a six-arm cylindrical handle dynamometer as seen in McDowell *et al.* could be used instead of the single-plain version (McDowell *et al.*, 2012). This calibration of the Tekscan™ would not have changed the overall results of our study, but the resultant values may have been more accurate.

6.4 Directions of future studies

This research and test method should be shared with standards developing organizations associated with protective gloves standards. Organizations such as the International Safety Equipment Association (ISEA) or ISO could then publish updated standards that include grip characterization.

The grip characterization should not only be for dry gloves, but for when gloves are wet with water or wet with oil. The results of which can then be used to inform consumers on the characteristics of glove grip before purchasing a protective glove. This would be a benefit to those occupations that involve exposure to wet or damp environments, such as employees in the fishing industry, farming, or firefighting; and occupations that involve exposure to oily or greasy environments, such as employees in the automotive repair or oil industries. Further research must be conducted to appropriately determine the grip characterization for these two additional circumstances. Certainly, the same %BHCV calculation can be used, but a method must be developed to standardize the amount of water and the amount of oil to be used in the test. The amount should reflect real-world situations and be readily reproducible from glove to glove.

In addition to expanding the test method for grip characteristics of protective gloves to include when wet with water and with oil; data collection on root-cause analyses where poor hand or glove grip was a contributing factor would be helpful. This would more fully explain the need to specify glove grip characteristics to help prevent workplace injuries. Safety professionals and glove manufacturers acknowledge that poor hand or glove grip could contribute to slips, trips, and falls especially on stairs and ladders; hence the rules of requiring certain handrails and guardrails in the workplace as well as advertisements touting glove grip. Currently, only anecdotal evidence is available to support the theory that poor hand or glove grip contributed to safety incidents. Even though no statistical data is available, a company in Denmark is manufacturing industrial handrails that they claim increase grip up to 300% in oily conditions. The handrails are currently being tested in the maritime industry and on offshore installations (Rasmussen, 2021). This is illustrative that good hand grip can contribute to the prevention of slips, trips, and falls.

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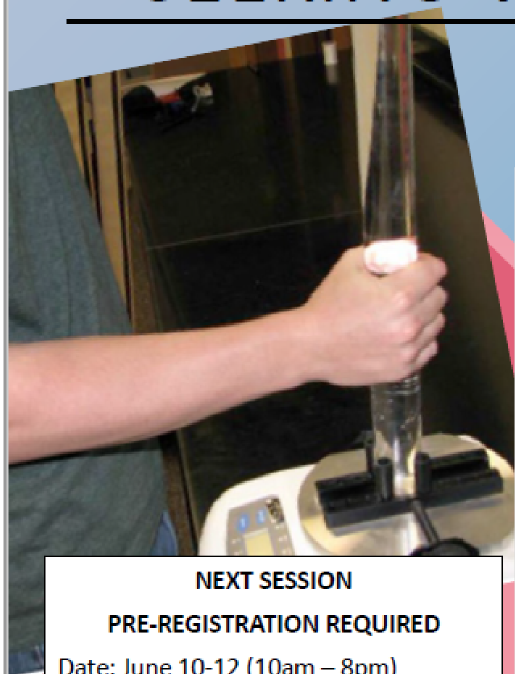
APPENDICES

Appendix A: Recruitment Flyer – Step One (Method Optimization)

University of Nebraska Medical Center

SEEKING VOLUNTEERS

ONE 60-MINUTE SESSION



This research project is to study human hand capabilities as they pertain to maximum torque.

Requirements:

Working age adults, 19 – 65 years of age

Cannot have conditions that may prohibit you from standing or using maximum grip strength and hand torque for 20 repetitions within one hour of time. These conditions may include, but are not limited to:

- Arthritis, Osteoarthritis, and Rheumatoid Arthritis
- Carpal Tunnel Syndrome
- Cubital Tunnel Syndrome
- Hand or arm fracture or recent surgery
- Ganglion cysts
- Finger, hand or arm tendonitis and tenosynovitis; including
  - De Quervain's Tendinitis or Tendinosis
  - Stenosing Tenosynovitis, Trigger Thumb, or Trigger Finger
  - Lateral epicondylitis or Tennis Elbow
  - Medial epicondylitis, Golfer's Elbow, or Baseball Elbow
  - Rotator cuff tendonitis
- Nerve damage affecting the upper extremities.

Interested?

Contact Doris Burns at daburns@unmc.edu or call/text 531-232-9658 for questions, more information and to pre-register.

NEXT SESSION

PRE-REGISTRATION REQUIRED

Date: June 10-12 (10am – 8pm)
June 17-19 (10am – 8pm)

Location: UNMC College of Public Health
40th & Dewey Ave.
Omaha, NE 68198

Doris Burns
c/o Chandran Achutan, PhD, CIH
Univ of Nebr Medical Center
984388 Nebraska Medical Center
Omaha, NE 68198-4388

IRB Number: 185-21-EP

Appendix B: On-Boarding Protocol – Step One (Method Optimization)

Test Subject "on-boarding" steps

1. Welcome & Thank You.
2. We must ask you these questions as part of the University Coronavirus Screening protocols:
    a. In the past 2 weeks have you had a new onset of fever, cough, shortness of breath, sore throat, chills, muscle aches, or loss of taste or smell?
    b. In the past 2 weeks have you had a new or worsening runny nose, nasal congestion, headache, or nausea/vomiting/diarrhea that is not related to a chronic condition or seasonal allergies?
    c. Have you been tested for COVID-19 in the past 2 weeks?
    d. Have you been asked to quarantine or been exposed to a person who has is confirmed positive for COVID-19 in the past 2 weeks?

    [NOTE: If any of these are "YES"; the participant must recuse themselves]

3. Because of COVID concerns, the University still requires facial coverings during the process. If you do not have one, one will be provided. If you refuse to wear one, you will have to withdraw from the research project.
4. We still request that you maintain 6' social distancing as much as possible during the testing procedures. There should be ample space to do so.
5. If you are willing to proceed, we will collect some data from you. [Hand them a clipboard with two copies of the Informed Consent (or two copies of their previously signed consent form) and the Data Collection Form].
    a. If you have not read and signed the "Informed Consent", please take the time to do so now. One copy is for you, and one is for us.
    b. Complete the top portion of the "Hand Torque Data Collection Sheet" where it says, "Completed by Participant". When you are finished with those two items, please return to have your hand measured and to continue the testing.
6. Measure the hand and record the Hand Girth, Digit 3 Link Length, Determined Hand Size, Start Time, Temperature and Humidity. Have them use hand sanitizer after the measurement and ensure their hands are dry. Ask them NOT to use hand sanitizer again until the testing is fully complete. This is to ensure consistent results. We are taking several precautions to ensure test equipment and the room remain in a sanitary condition.
7. Explain that they are to go to each station in the order listed on the Data Collection Sheet. That is, where the #1 is, go there first; #2, go there second and so on until they finish all 4 stations. The stations will be marked with the rod diameter size as it is shown on the Data Collection Sheet. The test proctor at each station will explain what to do.
8. Have Test Subject proceed to the testing area. When complete, have them return to the on-boarding table to receive the $30 VISA Gift Card and to record the ending time, temperature, and humidity on the Collection Sheet. Ask them to complete the bottom portion of the sheet if they would like to be contacted for the follow-on research – research will be similar but will include wearing gloves while torquing the acrylic rods. The follow-on research will take less time (about ½-hour) but they will receive the same (or more) for the stipend.

Appendix C: Data Collection Sheet – Step One (Method Optimization)

HAND TORQUE DATA COLLECTION SHEET

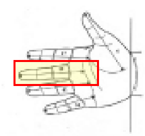
Completed by Participant:

Name*				Date	
Age at last birthday (yrs):		Sex at birth	M F	Declared Dominate Hand	L R

* - this data is not recorded in any databases. It is only needed to ensure correct data collection.

I have read and understand the Informed Consent. I believe that I meet all requirements to participate in this study.	Signature

Completed by Study Proctor:

Measured Hand Girth		_______ cm _______ in	Measured Digit 3 Link Length		_______ cm _______ in

Determined Hand Size: (based on hand girth – see size chart)	

SIZE CHART

MEASUREMENT: In Measurement	GLOVE SIZE: U.S. Sizing	European Sizing
6" (15.2 cm)	X-SMALL	6
7" (17.8 cm)	SMALL	7
8" (20 cm)	MEDIUM	8
9" (23 cm)	LARGE	9
10" (25 cm)	X-LARGE	10
11" (28 cm)	XX-LARGE	11
12" (30.5 cm)	XXX-LARGE	12

Time – Start:	Temperature – Start (°F):	Humidity – Start (%RH):

Randomized Order Sequence #				
Rod Diameter	1.125”	1.375”	1.625”	1.875”
Iteration #1	N-m	N-m	N-m	N-m
Iteration #2	N-m	N-m	N-m	N-m
Iteration #3	N-m	N-m	N-m	N-m
Iteration #4	N-m	N-m	N-m	N-m
Iteration #5	N-m	N-m	N-m	N-m

Time – End:	Temperature – End (°F):	Humidity – End (%RH):

Appendix D: Proctor Instructions – Step One (Method Optimization)

Station Testing Protocol

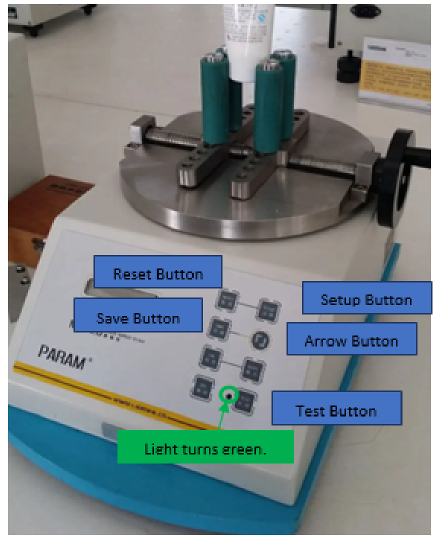
IMPORTANT NOTE: Conduct the test without the test subject's knowledge of the torque applied, that is, the test subject shall not be able to observe the reading from the torque meter or learn of the applied torque during any attempt to twist the rod. You may give the test subject their printout from the torque meter when done with all 5 iterations. Do not encourage the test subject at any time during the testing; their effort must be their natural maximum effort.

1. Conduct a bare hand torque measurement using a subject's declared dominant hand.
2. Set the torque meter to read a counter-clockwise torque for right-handed dominant test subjects. Set the torque meter to read a clockwise torque for left-hand dominant test subjects. (instructions on how to set these parameters are below.)
3. Test subjects stand such that they grab the acrylic rod with the elbow bent at a right angle and the upper arm against the side of the body.
4. If need be, adjust the height of the test apparatus to provide the proper body and arm orientation.
5. Have the subject stand with feet parallel, facing the testing apparatus, and shoulder width apart.
6. Have the subject place the non-dominant arm at the body's side during testing.
7. In the correct position, the engaged arm will be parallel to the upright body from the shoulder to the elbow and perpendicular to the ventral plane of the body from the elbow to the wrist. Photos of proper position are to the right:

8. With the bare hand firmly in grasp of the rod, each subject will make five successive attempts to twist the rod. The process is for the test subject to twist the rod with maximum torque for 5 seconds. Then, the subject will rest for 1 minute. This constitutes one iteration. The test subject will attempt 5 iterations in succession. Then, the subject will take a 5-minute rest period before going to the next station.
9. The test subject's rotation during the repetition shall be in the wrist rather than in the shoulder. An example of how the wrist looks before and after the twisting action can be seen below (right-hand dominant):
10. Record the maximum torque applied after each attempt on the Data Collection Form. Do not allow the test subject to know the results until finished will all 5 attempts.


In summary, at each station:

1. **NOTE THE DOMINANT HAND OF THE TEST SUBJECT**. All machines are set to right-hand dominant. If a person is left-handed, the machine parameters must be changed (info below).
2. **HAVE TEST SUBJECT STAND PROPERLY**. Stand with feet parallel, facing the testing apparatus, and shoulder width apart. Test subject grabs the acrylic rod with the elbow bent at a right angle and the upper arm against the side of the body. Place the non-dominant arm at the body's side during testing.
3. **PRESS THE "RESET" BUTTON**.
4. **TELL TEST SUBJECT**: I will be pressing a button; you will hear a beep. I will say "GO" and you start twisting the rod as hard as you can while I count out the 5 seconds. When I get to 5, stop twisting the rod. If you are right-handed, you will be twisting the rod COUNTER-clockwise. If you are left-handed, you will be twisting the rod CLOCKWISE. After the 5 seconds, I will start the timer for one minute. Then, we will do the exact same thing again until you have twisted the rod 5 times. You will, then, have 5 minutes to rest before going to the next station. Any questions? Are you ready?



5. **PRESS THE "TEST" BUTTON**. Light should turn green. Say "GO" and count aloud the 5 seconds from the timer. Test subject stops twisting the rod when you say "5".
6. **PRESS THE "TEST" BUTTON** again to stop the iteration. Start the one-minute rest period.
7. **RECORD THE NUMBER DISPLAYED ON THE TORQUE METER** onto the Data Collection Form.
8. **REPEAT STEPS 5 THRU 7 FOUR MORE TIMES.**
9. **RETURN THE DATA COLLECTION FORM (AND PRINTOUT) TO TEST SUBJECT.** The torque meter will automatically print out the Minimum, Maximum and Average Torque over the 5 iterations. You can give that to the test subject if they want it. Otherwise, it can be discarded. Return the Data Collection Form to the test subject so the other stations can do the same thing. When the Data Collection Form is completed, the test subject takes it back to the "on-boarding" station to finish the testing and receive their stipend.

TO CHANGE EQUIPMENT PARAMETERS FOR RIGHT VS. LEFT HAND TEST SUBJECTS:

1. **PRESS THE "RESET" BUTTON.**
2. **PRESS THE "SETUP" BUTTON.** You will get a reading of "SEL – 0 – F0" (The "F0" means for Right-handed people). If correct, press the RESET button again and begin the test. If not, then . . .
3. **PRESS THE ARROW BUTTON.** The reading will change to "SEL – 0 – F1 (The "F1" means for Left-handed people).
4. **PRESS THE "SAVE" BUTTON.** This will store the parameter.
5. **PRESS THE "RESET" BUTTON** and begin the testing process above. Ensure you return the meter parameters back when finished. Simply do the same thing above, but it will take 3 presses of the ARROW button to return it to "F0". Don't forget to press the "SAVE" button.
6. **TORQUE METER PARAMETER SETTINGS:**

0	F0 (for right-handed persons) F1 (for left-handed persons)	5	2-digit hour
1	05 (# of test iterations)	6	2-digit minute
2	21 (2-digit year)	7	2-digit second
3	06 (2-digit month)	8	01 (English)
4	2-digit day	9	01 (Print w/o font library)

Appendix E: Recruitment Flyer – Steps Two and Three (Grip Characterization and Grip Strength vs Grip Characterization)

Appendix F: On-Boarding Protocol – Steps Two and Three (Grip Characterization and Grip Strength vs Grip Characterization)

Test Subject "on-boarding" – Steps 2 & 3

1. Welcome & Thank You.
2. We must ask you these questions as part of the University Coronavirus Screening protocols:
    a. In the past 2 weeks have you had a new onset of fever, cough, shortness of breath, sore throat, chills, muscle aches, or loss of taste or smell?
    b. In the past 2 weeks have you had a new or worsening runny nose, nasal congestion, headache, or nausea/vomiting/diarrhea that is not related to a chronic condition or seasonal allergies?
    c. Have you been tested for COVID-19 in the past 2 weeks?
    d. Have you been asked to quarantine or been exposed to a person who has is confirmed positive for COVID-19 in the past 2 weeks?

    [NOTE: If any of these are "YES"; the participant must recuse themselves]

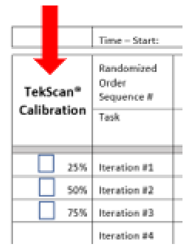
3. Because of COVID concerns, the University still requires facial coverings during the process. If you do not have one, one will be provided. If you refuse to wear one, you will have to withdraw from the research project.
4. We still request that you maintain 6' social distancing as much as possible during the testing procedures. There should be ample space to do so.
5. If you are willing to proceed, we will collect some data from you. [Hand them a clipboard with two copies of the Informed Consent (or two copies of their previously signed consent form) and the Data Collection Form].
    a. If you have not read and signed the "Informed Consent", please take the time to do so now. One copy is for you, and one is for us.
    b. Complete the top portion of the "Hand Torque Data Collection Sheet" where it says, "Completed by Participant". When you are finished with those two items, please return to have your hand measured and to continue the testing.
6. For these steps, we are only using centimeters to measure the hand girth and finger 3 length. Measure the hand and record the Hand Girth and Digit 3 Link Length; record this information in centimeters only. Determine the Hand Size based on the girth:

Hand Girth (in cm)	Hand Size
<13.9 cm	XXS
13.9 – 16.4 cm	XS
16.5 – 18.8 cm	S
18.9 – 21.4 cm	M
21.5 – 23.9 cm	L
24.0 – 26.4 cm	XL
26.5 – 29.24 cm	XXL
>29.24 cm	XXXL and larger

7. Record the Start Time. Temperature and Humidity need not be recorded. We are in an environmental chamber which is set automatically at the test parameters of 70ºF and 65% RH. If they wish to use hand sanitizer after the measurement, allow them to but explain that they must ensure their hands are

dry before conducting the testing. Ask them NOT to use hand sanitizer again until the testing is fully complete. This is to ensure consistent results. We are taking several precautions to ensure test equipment and the room remain in a sanitary condition.

8. Explain that they are to conduct the testing in the order that is listed on the data collection sheet. Some people will complete Step 3 BEFORE Step 2. If a person is completing both steps, the data collection sheets are stapled together in the order they are to conduct the testing (i.e. Step 2 or Step 3 data collection sheet is on top; the other is below with areas crossed off). You can tell the difference between the Data Collection Sheets because Step 3 has a "TekScan Calibration" Column.



9. Based on their hand size, give them a pair of gloves from each model that matches the hand. Tell them NOT to put them on until told to do so. The gloves have been kept at 70°F and if the test subject wears them too long, the gloves could get warm and throw our test data off. They must remove the glove between iterations. Tell them that they can keep the gloves after the testing is completed.
10. Tell them to return the completed paperwork at the end of the testing and they will receive their VISA Gift Card(s). [$50 is given for each step completed; however, only about 1/3 of the test subjects will participate in both].
11. Proceed to a torque meter or to Tekscan application; whichever is appropriate.

Appendix G: Data Collection Sheet – Step Two (Grip Characterization)

HAND TORQUE DATA COLLECTION SHEET

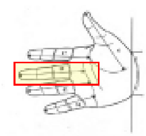
Completed by Participant:

Name*				Date	
Age at last birthday (yrs):		Sex at birth	M F	Declared Dominate Hand	L R

* - this data is not recorded in any databases. It is only needed to ensure correct data collection.

I have read and understand the Informed Consent. I believe that I meet all requirements to participate in this study.	Signature

Completed by Study Proctor:

Measured Hand Girth		________ cm ________ in	Measured Digit 3 Link Length		________ cm ________ in

Determined Hand Size:
(based on hand girth – see size chart)

SIZE CHART

MEASUREMENT: In Measurement	GLOVE SIZE: U.S. Sizing	European Sizing
6" (15.2 cm)	X-SMALL	6
7" (17.8 cm)	SMALL	7
8" (20 cm)	MEDIUM	8
9" (23 cm)	LARGE	9
10" (25 cm)	X-LARGE	10
11" (28 cm)	XX-LARGE	11
12" (30.5 cm)	XXX-LARGE	12

Time – Start:	Temperature – Start (°F):	Humidity – Start (%RH):

Randomized Order Sequence #			
Task	**Bare Hand**	**W/ Leather Glove**	**w/ Dipped Knit Glove**
Iteration #1	N-m	N-m	N-m
Iteration #2	N-m	N-m	N-m
Iteration #3	N-m	N-m	N-m
Iteration #4	N-m	N-m	N-m
Iteration #5	N-m	N-m	N-m

Time – End:	Temperature – End (°F):	Humidity – End (%RH):

If you would like to be contacted for follow-on research, please write your email address and phone number here:	Email:	Phone #:

Appendix H: Proctor Instructions – Steps Two and Three (Grip Characterization and Grip Strength vs Grip Characterization)

Station Testing Protocol – Steps 2 & 3

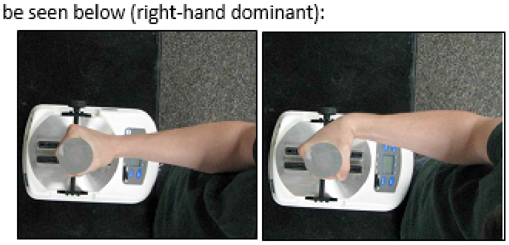
IMPORTANT NOTE: Conduct the test without the test subject's knowledge of the torque applied, that is, the test subject shall not be able to observe the reading from the torque meter or learn of the applied torque during any attempt to twist the rod. You may give the test subject their printout from the torque meter when done with all 5 iterations. Do not encourage the test subject at any time during the testing; their effort must be their natural maximum effort.

1. Determine the sequence of the torque testing. Some will have Step 2 conducted first (or it is the only Step) and some will have Step 3 conducted first). If Step 3 is conducted first, the test subject must have sensors applied – do that first. Each Step also has a randomized sequence, ensure you follow the sequence written on the data collection sheet for bare hand, glove #1, and glove #2. THIS IS VERY IMPORTANT.
2. Ensure that the test subject has a pair of each style of glove in the correct size. Please check the documentation to ensure it was calculated correctly and that the glove size corresponds to the measurement.
3. Conduct torque measurements using a subject's declared dominant hand.
4. Set the torque meter to read a counterclockwise torque for right-handed dominant test subjects. Set the torque meter to read a clockwise torque for left-hand dominant test subjects. (Instructions on how to set these parameters are below.)

Hand Girth (in cm)	Hand Size
<13.9 cm	XXS
13.9 – 16.4 cm	XS
16.5 – 18.8 cm	S
18.9 – 21.4 cm	M
21.5 – 23.9 cm	L
24.0 – 26.4 cm	XL
26.5 – 29.24 cm	XXL
>29.24 cm	XXXL and larger

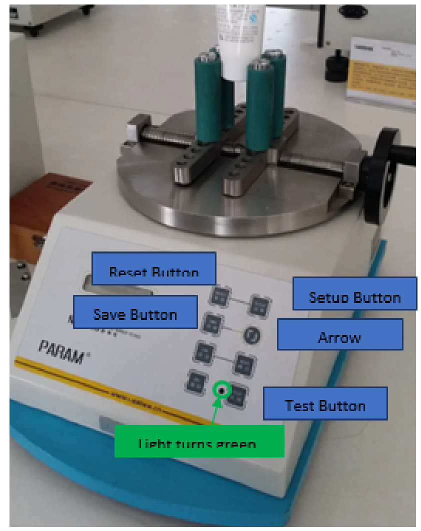
5. Test subjects stand such that they grab the acrylic rod with the elbow bent at a right angle and the upper arm against the side of the body.
6. If need be, adjust the height of the test apparatus to provide the proper body and arm orientation.
7. Have the subject stand with feet parallel, facing the testing apparatus, and shoulder width apart.
8. Have the subject place the non-dominant arm at the body's side during testing.
9. In the correct position, the engaged arm will be parallel to the upright body from the shoulder to the elbow and perpendicular to the ventral plane of the body from the elbow to the wrist. Photos of proper position are to the right:

10. With the hand firmly in grasp of the rod, each subject will make five successive attempts to twist the rod. The process is for the test subject to twist the rod with maximum torque for 5 seconds. Then, the subject will rest for 1 minute. This constitutes one iteration. The test subject will attempt 5 iterations in succession. Then, the subject will take a 5-minute rest period before going to the next step in the sequence.
11. The test subject's rotation during the repetition shall be in the wrist rather than in the shoulder. An example of how the wrist looks before and after the twisting action can be seen below (right-hand dominant):
12. Record the maximum torque applied after each attempt on the Data Collection Form. Do not allow the test subject to know the results until finished will all 5 attempts.
13. When conducting the test with gloves on; ensure that the test subject removes the glove between iterations to keep gloves from getting too warm.



In summary, at each station:

1. **NOTE THE DOMINANT HAND OF THE TEST SUBJECT.** All machines are set to right-hand dominant. If a person is left-handed, the machine parameters must be changed (info below).
2. **ENSURE TEST SUBJECT'S HAND SIZE AND GLOVE SIZE ARE CORRECT.**
3. **HAVE TEST SUBJECT STAND PROPERLY.** Stand with feet parallel, facing the testing apparatus, and shoulder width apart. Test subject grabs the acrylic rod with the elbow bent at a right angle and the upper arm against the side of the body. Place the non-dominant arm at the body's side during testing.
4. **PRESS THE "RESET" BUTTON.**
5. **TELL TEST SUBJECT**: I will be pressing a button; you will hear a beep. You may place your hand onto the rod. I will say "GO" and you start twisting the rod as hard as you can while I count out the 5 seconds. When I get to 5, stop twisting the rod. If you are right-handed, you will be twisting the rod COUNTER-clockwise. If you are left-handed, you will be twisting the rod CLOCKWISE. After the 5 seconds, I will start the timer for one minute. Then, we will do the exact same thing again until you have twisted the rod 5 times. You will, then, have 5 minutes to rest before going to the next step in the sequence. Any questions? Are you ready?



6. **PRESS THE "TEST" BUTTON.** The machine will beep, and the light should turn green. The test subject can put their hand on the rod. Say "GO" and count aloud the 5 seconds from the timer. Test subject stops twisting the rod when you say "5".
7. **PRESS THE "TEST" BUTTON** again to stop the iteration. **<u>If test subject is wearing a glove, it should be removed for the one-minute rest period</u>**. Start the one-minute rest period.
8. **RECORD THE NUMBER DISPLAYED ON THE TORQUE METER** onto the Data Collection Form.
9. **REPEAT STEPS 6 THRU 8 FOUR MORE TIMES.**
10. **RETURN THE DATA COLLECTION FORM (AND PRINTOUT) TO TEST SUBJECT.** The torque meter will automatically print out the Minimum, Maximum and Average Torque over the 5 iterations. <u>It is a good idea to compare your written data to the printout (minimum and maximum)</u>. Give printout to the test subject if they want it, otherwise, discard. The test subject will use the same torque meter / acrylic rod for all tests. When the Data Collection Form is completed, the test subject takes it back to the "on-boarding" station to finish the testing and receive their stipend.

TO CHANGE EQUIPMENT PARAMETERS FOR RIGHT VS. LEFT HAND TEST SUBJECTS:

1. **PRESS THE "RESET" BUTTON.**
2. **PRESS THE "SETUP" BUTTON.** You will get a reading of "SEL – 0 – F0" (The "F0" means for Right-handed people). If correct, press the RESET button again and begin the test. If not, then . . .
3. **PRESS THE ARROW BUTTON.** The reading will change to "SEL – 0 – F1 (The "F1" means for Left-handed people).
4. **PRESS THE "SAVE" BUTTON.** This will store the parameter.
5. **PRESS THE "RESET" BUTTON** and begin the testing process above. Ensure you return the meter parameters back when finished. Simply do the same thing above, but it will take 3 presses of the ARROW button to return it to "F0". Don't forget to press the "SAVE" button.
6. **TORQUE METER PARAMETER SETTINGS:**

0 F0 (for right-handed persons)
  F1 (for left-handed persons)
1 05 (# of test iterations)
2 21 (2-digit year)
3 07 (2-digit month)
4 2-digit day
5 2-digit hour
6 2-digit minute
7 2-digit second
8 01 (English)
9 01 (Print w/o font library)

Appendix I: Data Collection Sheet - Step Three (Grip Strength vs Grip Characterization)

HAND TORQUE DATA COLLECTION SHEET

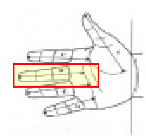
Completed by Participant:

Name*				Date	
Age at last birthday (yrs):		Sex at birth	M F	Declared Dominate Hand	L R

* - this data is not recorded in any databases. It is only needed to ensure correct data collection.

I have read and understand the Informed Consent. I believe that I meet all requirements to participate in this study.	Signature

Completed by Study Proctor:

Measured Hand Girth		________ cm ________ in	Measured Digit 3 Link Length		________ cm ________ in

Determined Hand Size: (based on hand girth – see size chart)	

SIZE CHART

In Measurement	U.S. Sizing	European Sizing
6" (15.2 cm)	X-SMALL	6
7" (17.8 cm)	SMALL	7
8" (20 cm)	MEDIUM	8
9" (23 cm)	LARGE	9
10" (25 cm)	X-LARGE	10
11" (28 cm)	XX-LARGE	11
12" (30.5 cm)	XXX-LARGE	12

(MEASUREMENT; GLOVE SIZE)

	Time – Start:	Temperature – Start (°F):	Humidity – Start (%RH):

TekScan® Calibration	Randomized Order Sequence # / Task	Bare Hand	w/ Leather Glove	w/ Dipped Knit Glove	TekScan® Calibration
☐ 25%	Iteration #1	N-m	N-m	N-m	☐ 25%
☐ 50%	Iteration #2	N-m	N-m	N-m	☐ 50%
☐ 75%	Iteration #3	N-m	N-m	N-m	☐ 75%
	Iteration #4	N-m	N-m	N-m	
	Iteration #5	N-m	N-m	N-m	

	Time – End:	Temperature – End (°F):	Humidity – End (%RH):

Appendix J: Tekscan™ Grip™ System Information - Step Three (Grip Strength vs Grip Characterization)

Grip™ System

Tactile Grip Force & Pressure Measurement

The Grip™ system measures and evaluates static and dynamic pressures from grasping objects. Grip measures interface pressure for human hand and finger gripping applications to assess comfort, design, and ergonomics. The system is used to improve design for a more ergonomically sound product, study carpal tunnel and repetitive motion syndrome, or analyze the human hold on various tools and sports equipment. It is an ideal tool for collecting vital information and insight to enhance product design, manufacturing, quality, and research.

KEY FEATURES & BENEFITS

System

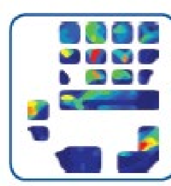
- Simultaneous measurement of left and right hands
- Numerous independent sensing elements for localized detection of pressure points
- One subject can grip several objects, in many ways once the hand is instrumented
- High scanning rates of up to 750Hz (tethered version)

Sensor

- Sensor form factor allows for full range of hand motion
- Paper-thin sensor does not affect the grip "feel"
- One size fits all
- Durable and reusable

1. Connect

2. Collect



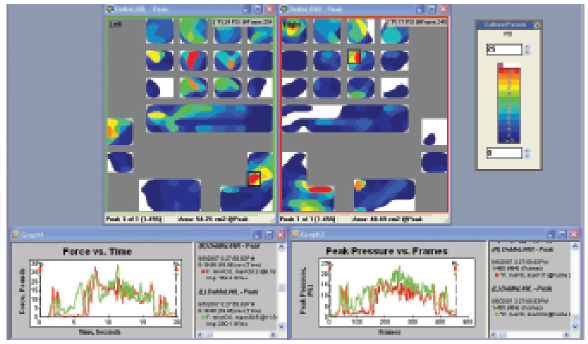
3. Analyze

Grip System Flyer

Tekscan

KEY SOFTWARE FEATURES

- Access real time or recorded data in 2D & 3D
- Key metrics; total force, peak pressures, and center of force
- Multiple graph options to plot data
- View and compare multiple test results simultaneously
- Ability to attach a digital image to each frame of a Tekscan movie
- Export data to ASCII or AVI files



Example of grip pressure data while subject operated an industrial floor polisher

APPLICATIONS

- Ergonomics
  - Vibration Studies
  - Carpal tunnel syndrome
  - Heavy lifting
- Improve product design
  - Consumer goods
  - For the elderly and physically disabled
- Analyze grip in sports applications
  - Baseball bat
  - Golf club
  - Tennis racquet
- Robotics

Grip Sensor Specifications

Sensor Technology	Resistive
Pressure Range	0-50 psi
Sensor Thickness	0.15 mm (0.007 in.)
Sensel Density	6.2 sensels per square centimeter (40.0 sensels per square inch)
Sensing Area	5 independent fingers, each containing multiple sensing regions (18 regions total)
No. of Sensing Elements	349

CONNECTION TYPES

The Grip system is available tethered or untethered for increased mobility and range of measurement. Your specific application will determine the best-suited connection type.

System Specifications

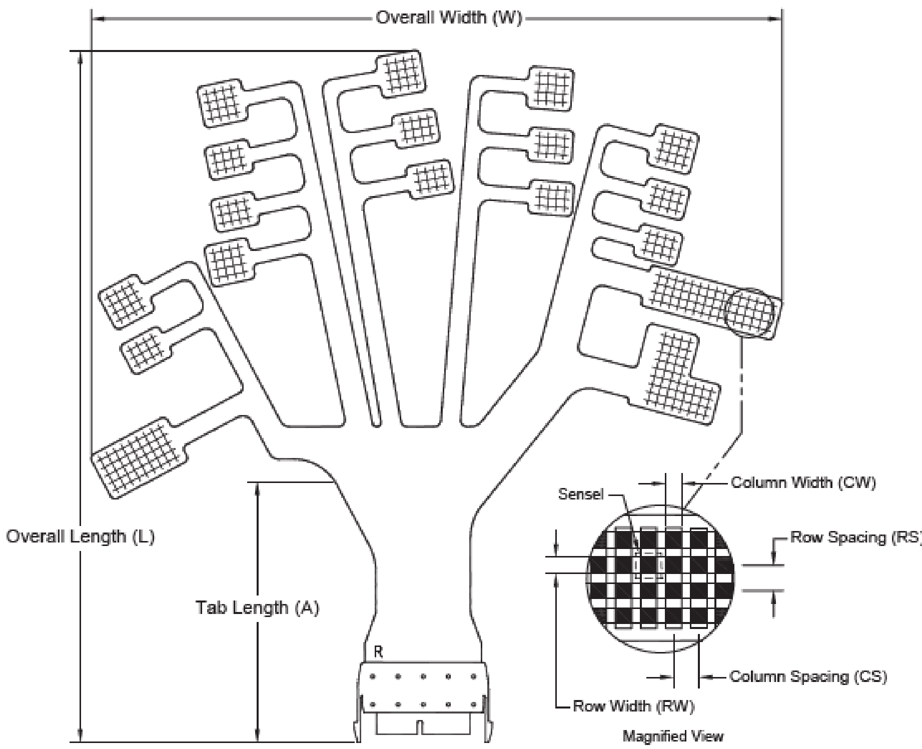
Connection Type	Tethered	Wireless	Datalogger
Scan Speed	Up to 750 Hz	Up to 200 Hz	Up to 750 Hz
Maximum Distance	Up to 100 ft (30.5 m)	Up to 328 ft (100 m)	Unlimited

CONTACT US | FREE DEMONSTRATION

+1.617.464.4282 | 1.800.248.3669 | info@tekscan.com | www.tekscan.com/pm

Tekscan® Pressure Mapping Sensor 4256E

Pressure Mapping, Force Measurement, and Tactile Sensors



General Dimensions			Sensing Region Dimensions								Summary	
Overall Length *L*	Overall Width *W*	Tab Length *A*	Matrix Width *MW*	Matrix Height *MH*	Columns *CW*	Columns Pitch *CS*	Columns Qty.	Rows *RW*	Rows Pitch *RS*	Rows Qty.	Total No. of Sensels	Sensel Spatial Resolution
(mm) 330.7	(mm) 329.9	(mm) 124.7	(mm) Various	(mm) Various	(mm) 2.5	(mm) 4.0	36	(mm) 2.5	(mm) 4.0	23	349	(sensel per sq-cm) 6.2
(in) 13.02	(in) 12.99	(in) 4.91	(in) Various	(in) Various	(in) 0.100	(in) 0.158	36	(in) 0.100	(in) 0.158	23	349	(sensel per sq-in) 40.3

Pressure Ranges

kPa	345
psi	50

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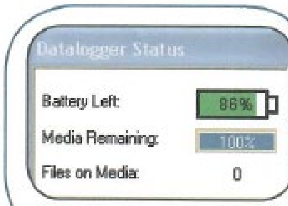
Appendix K: Tekscan™ VersaTek Datalogger Setup & Usage Quick Start Guide - Step Three (Grip Strength vs Grip Characterization)

Tekscan®

VersaTek Datalogger Setup & Usage Quick Start Guide

Initializing the Datalogger Unit

Before you can use the VersaTek Datalogger to take recordings, and before each recording session, you must initialization and calibrate the sensors while the Datalogger unit is connected to the PC. Once this procedure has been performed, you can take recordings.



Step 3: Datalogger Status indicators.

STEP 1. Connect the mini-USB cable to the VersaTek Datalogger unit, and connect the other end to the computer's USB port.

STEP 2. Turn on the VersaTek Datalogger by pressing and holding the Power Switch located on the front panel for four seconds. The system will count down from 10 seconds (shown on the front display of the unit). Wait until the display reaches zero.

STEP 3. Open the Tekscan software. The on-screen status indicator displays in the top right corner of the main software window. This dialog indicates the following:

- **Battery Left:** indicates the power remaining on the battery.
- **Media Remaining:** indicates how much space is available on the Micro-SD card.
- **Files on Media:** indicates how many movies are stored on the Micro-SD card.

STEP 4. Open a real-time window(s) by clicking the "New Recording" button on the Toolbar.

STEP 5. Perform a calibration on the sensor(s) and set up the Data Acquisition Parameters for the trials you will be recording.

STEP 6. Disconnect the device from the Computer by removing the USB cable from the unit. The VersaTek Datalogger unit is now initialized and ready to take recordings.

Note: Once the Datalogger Unit is disconnected from the computer, you can turn the unit off until you are ready to take your recordings. The recording settings on the device will not be lost.

Taking a Recording

This procedure is used to take a recording, transfer the recording to your computer, view it onscreen, and save it to your computer. Follow the procedure below after you have completed the previous initialization.

STEP 1. Confirm that the device is turned on. Power Switch, Datalogger Storage Status indicator, Battery Strength Status indicator, and Recordings Status indicators are green and indicate the system is ready to Record. The Micro-SD Card Reader light is blue to indicate that data can be recorded to the card.

STEP 2. Ensure the Patient is ready to take a recording. When ready, press the Record button on the front panel of the VersaTek Datalogger Unit. The system is now recording data to the attached Micro-SD card. Proceed with the trial, and when you are finished recording, press the Record button on the front panel of the unit once again. This stops recording.

Step 1: The VersaTek Datalogger Unit is ready to take a recording.

Step 1b: The Micro-SD card and USB to Micro-SD Converter. Ensure this is inserted into the Micro-SD slot of the VersaTek Datalogger Unit.

Step 1c: The Micro-SD card inserted into the VersaTek Datalogger Unit.

STEP 3. Insert the mini-USB cable into the mini-USB port of the VersaTek Datalogger Unit. Connect the other end of the USB cable into the computer. The computer will identify the connected device automatically.

STEP 4. The movies are automatically downloaded to your computer. At this point, the recorded file (or files, if multiple files were recorded) is moved to the local computer and the recording(s) opens on-screen. It is important to note that at this point the recorded files are not yet saved. You must manually save each of the recorded files. Once this is done, you can exit the software.

> **Note: If you attempt to exit without saving any of the recordings open on-screen, a prompt opens asking if you would like to save the files. You can elect to save them or exit the program without saving. However, if you exit without saving the files, they will be lost and cannot be retrieved later.**

STEP 5. To save the files, go to File > Save Movie . The "Add Movie to Database" dialog opens. Select the patient associated to the movie, and click the Save button. The movie is now saved in your patient database.

STEP 6. To turn off the Datalogger unit, press and hold the Power Switch located on the front panel for four seconds. The system shuts down and all lights on the unit turn off.

Manually Downloading Movie Files

The following outlines manually downloading movie files from the Datalogger Unit.

- Auto Load Recordings from Datalogger: By default, the movies are automatically downloaded and transferred to your computer. You can override this setting by going into Options > Set User Preferences > Datalogger tab, and removing the checkmark from this checkbox (see Image 3). If you deselect the "Auto Load" feature, you will have to manually transfer movie files from the Micro-SD card to the computer. See next bullet point.

- To manually download files from the VersaTek Datalogger, do one of the following:

  A) Remove the Micro-SD card from the VersaTek unit. Insert it into your computer's USB port. If the software is open, it automatically detects the card. If the software is not open, start the software, and click the "Open Recordings from Media" Toolbar icon to open the .vrr files (see Image 4). Note that this only copies movies from the SD Card. Movies are kept on the Card.

  B) If the "Auto Load" feature is turned off, and you connect the VersaTek Datalogger to the computer with the Micro-SD card inside the Datalogger, you will need to click on the "Load Recordings from Datalogger" icon on the Toolbar (see Image 5). Note: This should only be necessary if you have disconnected and reconnected the VersaTek Datalogger Unit to the computer via the USB cable.

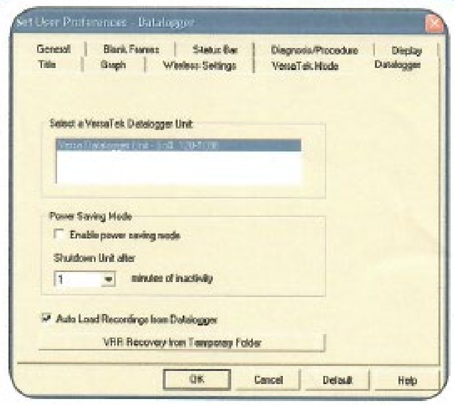


Image 3: The Datalogger User Preference tab with "Audo Load Recordings from Datalogger" setting.

Image 4: The "Open Recordings from Media" Toolbar Icon.

Image 5: The "Load Recordings from Datalogger" Toolbar Icon.

For more information on using the Datalogger system, consult your software Manual or Help File.