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EXTRA-VEHICULAR ACTIVITY (EVA) GLOVE EVALUATION TEST PROTOCOL

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Astrionics Laboratory
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One of the most critical components of a space suit is the gloves, yet gloves have traditionally presented significant design challenges. With continued efforts at glove development, a method for evaluating glove performance is needed. This paper presents a pressure-glove evaluation protocol. A description of this evaluation protocol, and its development is provided. The protocol allows comparison of one glove design to another, or any one design to bare-handed performance. Gloves for higher pressure suits may be evaluated at current and future design pressures to drive out differences in performance due to pressure effects. Using this protocol, gloves may be evaluated during design to drive out design problems and determine areas for improvement, or fully mature designs may be evaluated with respect to mission requirements. Several different test configurations are presented to handle these cases. This protocol was run on a prototype glove. The prototype was evaluated at two operating pressures and in the unpressurized state, with results compared to bare-handed performance. Results and analysis from this test series are provided, as is a description of the configuration used for this test.

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ABBREVIATIONS

AFD	Aft Flight Deck
ARC	Ames Research Center (NASA)
ASEE	American Society for Engineering Education
CIS	Commonwealth of Independent States
DOF	Degrees of Freedom
EMG	Electromyographic
EMU	Extravehicular Mobility Unit (space suit)
EV	Extravehicular
EVA	Extravehicular Activity
EVALS	EVA Limitations Study
FRL	Flight Robotics Laboratory
HGA	High Gain Antenna
HST	Hubble Space Telescope
ITMG	Integrated Thermal Micrometeoroid Garment
IV	Intravehicular
JSC	Johnson Space Center (NASA)
KSU	Kansas State University
MIT	Massachusetts Institute of Technology
MPT	Mini Power Tool
MSC	Mobile Servicing Center
MSFC	Marshall Space Flight Center (NASA)
NASA	National Aeronautics and Space Administration
NBS	Neutral Buoyancy Simulator
NSTS	National Space Transportation System

OU	University of Oklahoma
PAD	PFR Attachment Device
PFMA	Proto-Flight Manipulator Arm
PFR	Portable Foot Restraint
PKM	Perigee Kick Motor
PLB	Payload Bay
POCC	Payload Operations Control Center
PRD	Payload Retention Device
PRLA	Payload Retention Latch Assembly
PSA	Provisions Stowage Assembly
RTI	Research Triangle Institute
RMS	Remote Manipulator System
ROM	Range of Motion
SA	Solar Array
SBU	Staging and Boost Unit
SRMS	Shuttle RMS
S.S. *Freedom*	Space Station *Freedom*
STS	Space Transportation System
THURIS	The Human Role In Space
TMG	Thermal Micrometeoroid Garment
UASE	UARS Airborne Support Equipment
UARS	Upper Atmosphere Research Satellite
WETF	Water Evaluation Training Facility
WPI	Worcester Polytechnic Institute
ZPS	Zero Prebreathe Suit

TECHNICAL MEMORANDUM

EXTRAVEHICULAR ACTIVITY GLOVE EVALUATION TEST PROTOCOL

INTRODUCTION

A. Summary

Extravehicular activity (EVA) has been a part of space activities since astronauts and cosmonauts performed spacewalks in the 1960's. During the United States Apollo program, astronauts went EVA on the lunar surface. Shuttle astronauts have performed satellite rescue and repair requiring EVA. Space station plans call for onorbit assembly to be done by astronauts and telerobots working together.[1] Recent studies have indicated the need for considerable amounts of servicing for the space station.[2 3] At the same time, studies have shown a marked increase in time to perform tasks between EVA-gloved hands and the ungloved human hand.[4] Together these studies point to the need for increased capability for the EVA astronaut, especially in gloved-hand dexterity.

NASA has attempted to find a means for increasing the dexterity of the astronaut's extravehicular mobility unit (EMU) gloved hand. In the current shuttle EMU suit, when fully pressurized, the hand has very little mobility—especially in independent finger movement. Dexterous actions, such as activating a trigger for a power tool or putting a nut on a bolt, require significant astronaut exertion to operate the fingers independently. Discomfort, abrasions, and fatigue have even been recorded after glove use.[5]

To verify glove performance, a test methodology for evaluating one glove design versus another and providing a comparison to the performance of the human hand, needs to be devised. Finding a method for quantifying hand/glove performance has not been easy. A performance metric can be broken down into many factors; among these are fatigue, dexterity, and comfort. In addition, many of these factors are interrelated and difficult to measure separately.

Testing gloved hand performance involves concepts from several disciplines. Evaluations performed in the course of reenabling a disabled hand, designing a robotic end effector or master controller, or hard-suit design have all yielded relevant information, and, in most cases, produced performance test methods. Most times, these test methods have been primarily oriented toward their parent discipline. Recently, tests designed for robotic end effector and gloved hand evaluation have been proposed.[6] For space operations, a comparative test which provides a way to quantify glove and end effector performance would be useful in dividing tasks between humans and robots. Such a test would rely heavily on sensored measurement, as opposed to questionnaires, to produce relevant data.

The tests developed to date have concentrated on evaluating the performance of existing gloves. Evaluation of existing gloves' performance is valuable in order to determine areas for future improvements in glove design. However, evaluations performed earlier in the glove design process can help produce a better baseline design. A realistic glove evaluation protocol needs to be flexible enough to handle variance in the availability of test subjects. In many cases, test subjects are difficult to find; so while more test subjects may be desirable, the test protocol should be able to handle less than ideal conditions and still produce meaningful results. In some cases, such as evaluating a mature design, experienced users may be preferable as test subjects. When evaluating less mature designs, inexperienced test subusers may be preferable as test subjects. When evaluating less mature designs, inexperienced test subjects may provide less biased results. The use of inexperienced test subjects also allows prototypes to be evaluated before bringing the design to the final user population, providing more flexibility in test location and test subject selection. In cases where test subjects are not the final user population, differences between those subjects and the final users must be determined. This report presents a protocol for evaluating EVA glove performance at any time in the design process from early prototype to mature design. Existing gloves may be compared to other gloves, or evaluated with respect to mission requirements. Proposed modifications to existing designs may be evaluated before final implementation. Design prototypes may be evaluated to indicate improved design directions before having completed the glove development. Test performance with a limited number of test subjects is possible; variations in test configuration based on test subject availability are presented. Glove testing of an early prototype glove using this protocol is described in section VI.

B. Overview

A brief summary of NASA EVA glove development is presented in section II. Glove evolution from the Gemini program through the series 4000 gloves has progressed through the incorporation of several technologies. Other technologies have been tried on nonflight versions of the gloves, such as the LRL glove. Glove design issues are discussed, and some university glove research projects are presented. One constant in flight glove development has been crew evaluation and acceptance, as the astronauts are the final end users of the glove technology. Even so, an increase in engineering development and evaluation of gloves before final review by the astronauts has been suggested.[7,8]

Section III discusses previous studies in EVA glove evaluation. EVA gloves are a critical component of the overall EVA suit, and their design has a direct bearing on the suited crewmember's performance of EVA tasks. The evaluation of glove design and performance is dependent on an understanding of the mission needs. Several projected and actual EVA missions are discussed in terms of glove-influenced parameters.

Section IV provides a concise description of the test protocol presented in this report. A rationale and methodology are presented, and a short step-by-step guide for using this protocol follows. A diagram of inputs and expected outputs is given. Since this protocol relies on comparison of gloved versus bare hand performance, a discussion of basic hand capabilities is provided.

An indepth discussion of the test protocol design is presented in section V. The experimental design, including statistics, subject selection and classification, and a description of the necessary measurements is provided. Test configurations for evaluating early and mature glove designs, using more or fewer test subjects are discussed. An example test configuration for an 8 psi glove, with several sizes available, and a full complement of test subjects is presented. Optional test configurations for 4.3 psi gloves, or a limited range of glove sizes or test subjects are also discussed. The specific tests administered to ascertain gloved-hand performance in several categories are presented in detail.

Section VI describes the evaluation of a glove prototype conducted using this protocol. This is the actual test series conducted at Vanderbilt University, Nashville, TN. The glove tested is the shell, before incorporation of the active control system, of a glove prototype developed by John Main of Vanderbilt University. The protocol configuration, reasons for using that configuration, the actual tests given, and the test apparatus used are described. A discussion of noteworthy aspects of the test results is provided. The complete test results are presented in appendix D.

Improvements to this protocol, and directions for future research are discussed in section VII. Several new technologies will soon be mature enough to provide meaningful inputs to glove and manipulator evaluation, and could be added to enhance the protocol described here. Future tests which could be conducted on the Vanderbilt glove prototype are discussed, including underwater testing and a comparison of the glove with the active control system to the tests run on the shell.

A discussion of EVA activities and how these activities impact glove design and evaluation is presented in appendix A. The hand questionnaires used in testing are provided in appendix B. Appendix C discusses the video image analysis technique used in these tests, and a relatively inexpensive, yet useful, method for evaluating video data in tests of this type. The Vanderbilt University glove prototype test data are provided in appendix D.

II. EVA GLOVE DEVELOPMENT

A. Glove History

Early EVA gloves were strongly influenced by military pressure suit glove design. Military pressure suits were developed for aircraft flights in excess of 50,000 ft. During the Mercury program, a pressurized suit was kept as a backup for cabin pressure; however for the Gemini program, a full EVA suit was necessary.[9] The Gemini program produced NASA's first EVA glove. The basic glove was two layers: a bladder and outer restraint layer, with an integrated thermal micrometeoroid garment (ITMG) outer glove. The glove had nonconstant volume joints and used straps and tapes to maintain the gloves shape.[10]

For the Apollo program, gloves had to work in both Earth and lunar orbit and on the lunar surface. These gloves would be exposed to more extreme temperature ranges and more severe abrasion conditions.[11] Apollo produced the first all NASA EVA system. Gloves were designed for operation in microgravity and one-sixth gravity. The A7L EVA glove design incorporated lunar surface thermal requirements which ranged from –250 to 250 °F. The Apollo glove had an integral bladder/restraint layer and an ITMG outer glove. A fingerless outer glove was worn to reduce abrasion wear to the glove.[10] During the Apollo program, the LRL glove was built. This glove is a technology reference point in that it had a rolling convolute wrist joint and used a double layer of linknet in the metacarpal joint of the thumb and fingers.[7]

Skylab built on the Apollo glove technology, with more layers being built into the ITMG. Although the *Skylab* gloves did not have to handle the level of abrasion found in lunar conditions, these gloves did represent the first U.S. gloves designed for EVA repair capability.[7]

Gloves for the National Space Transportation System (NSTS) were designed as the first U.S. long-duration EVA work glove. These gloves were also designed to be reusable.[7, 10] Shuttle-era gloves have been through several generations. The first shuttle glove, the series 1000, flew from 1981 to 1984. One problem with the series 1000 glove was the short operational life of the glove's bladder. A series 2000 prototype was built but never flown. The series 3000 built upon the 1000 design, and the bladder's useful life was significantly increased. Although the shuttle gloves come in standard sizes, the series 3000 gloves added finger and thumb length adjustments to improve fit to the individual astronaut. A series 4000 glove was introduced in 1986. The 4000 series is the current EMU glove. A modified ILC Dover 8.3 psi model glove is the series 5000 glove. The series 5000 glove has been a test model only, and not used in flight.[10]

Shuttle gloves incorporated a bladder and outer restraint layer, an ITMG outer glove, and used tucked fabric and nonconstant volume joints. A palm bar is used to help control swelling of the glove when pressurized. Finger caps aid in grip and tactile sensing.[7] The current ITMG has seven layers; four layers of aluminized Mylar™ and three layers of nonwoven Dacron™ scrim.[7 12] The restraint layer and glove bladder mold are shown in figures 1 and 2 taken from the EVA Gloves NASA Workshops proceedings.[7] Figure 3, from the NASA Standard 3000, shows the shuttle EVA glove thermal micrometeoroid garment (TMG).[13]

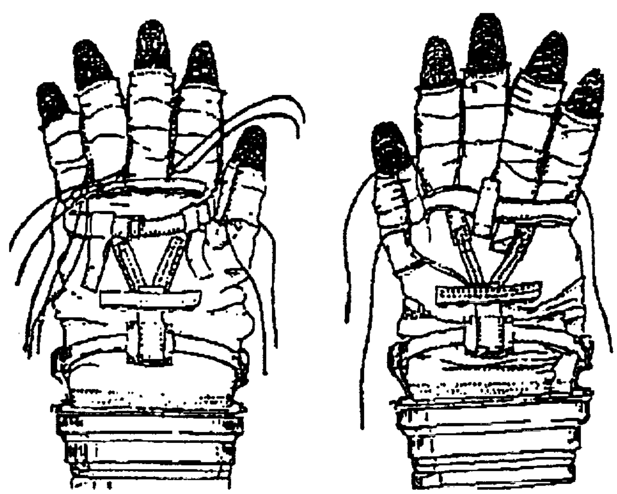


Figure 1. Glove restraint.

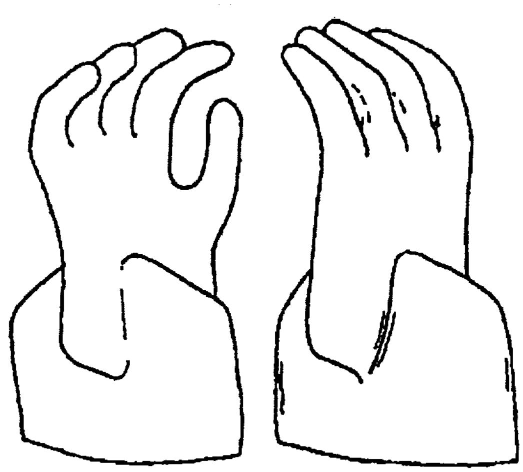


Figure 2. Glove bladder mold.

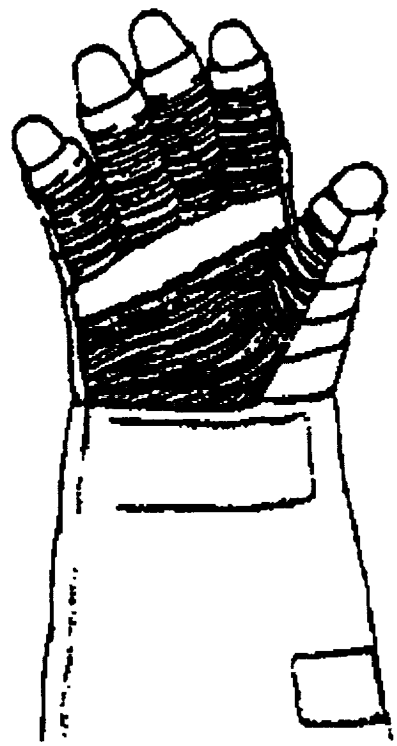


Figure 3. Shuttle EVA glove TMG.

Studies of higher operating pressure gloves have been performed since the 1960's, including a four phase contract from which the Acurex Corporation delivered two pairs of 8.0 psi gloves to NASA Ames in 1975.[10 14] Gloves with an operating pressure of 8.3 psi have been developed for the zero prebreathe suit (ZPS) program by ILC Dover and the David Clark Company. Astronaut testing of these gloves has generally given favorable results.[10 15 16]

Today's Series 4000 gloves are fitted for each astronaut. Future plans may include completely customizing gloves for each astronaut.[17] There is no preselected subgroup of astronauts for EVA. Rather, astronauts are trained in EVA as time permits, and then fitted for gloves. Standard sizes of gloves are available, however individual modifications are often required due to variations in hand conformation, even among similarly sized hands. Individuals of similar hand size may have slight differences in finger length or the bend of a specific finger which could interact differently with a glove for that sized hand. The custom fit approach was recommended for optimum performance and overall glove fit.[17]

Once fitted, gloves are sized for the astronaut's fingers using pull cords which run along the sides of each finger of the glove. This method is used to fine tune glove fit after the glove has been shown to basically fit the individual astronaut.[17]

B. Glove Design Issues

It could be argued that the goal of glove designs should be to enhance/enable the performance of a particular task. In this case, a glove would be designed to optimize performance in a particular area, while possibly allowing nonencumbering reductions of capability in other areas. This has been done to some extent in EVA glove design; gloves have been designed for orbital versus lunar surface EVA missions.[7]

In attempting to define hand/glove functions, J. Kosmo listed the following bare hand functional operations (1985): grasping, finger/thumb opposition, wrist articulation, and tactile feedback. He then listed the gloved hand mobility performance requirements to meet each of those areas. Prehensile grasping required metacarpal flexion/extension and individual finger and thumb flexion/extension; finger/thumb opposition required that a glove allow individual finger and thumb motions; wrist articulation involved flexion/extension, abduction/adduction, and rotation; while tactile feedback required allowing function of hand sensory nerve endings.[7]

C. Glove Design Research

In 1985, NASA awarded EVA glove design research grants to four universities. Each university was to try to design an improved glove. The participating schools were Worcester Polytechnic Institute (WPI), University of Oklahoma (OU), Massachusetts Institute of Technology (MIT), and Kansas State University (KSU). The grant contract was administered by the American Society for Engineering Education (ASEE)[7].

The glove designs were varied, with enhanced joint flexibility and control of ballooning in the palm as recurrent themes. In addition, the schools did some testing of their designs. The University of Oklahoma, in particular, conducted a set of tests to determine tactility, strength, and dexterity using bare-handed performance as a control, along with testing various non-EVA gloves. A more detailed description of the glove designs may be found in the "NASA Workshop Proceedings: Extravehicular Activity Gloves" prepared by the Research Triangle Institute (RTI).[7]

In addition to the above mentioned university studies, in June of 1985 NASA and the RTI hosted a 3-day workshop on EVA gloves. During the workshop, four separate subgroups were formed to study different glove design issues. These groups were hand function, hand protection, hand augmentation, and glove fabrication. The hand function group in particular, as well as a portion of the total workshop effort, concentrated on the need to develop a quantitative analysis and testing program for evaluating EVA gloved-hand performance.[7] A short discussion of the workshop efforts in this area follows.

EVA analyses have previously been done by videotaping astronaut motions during missions or underwater simulations. While this provides information on types of motion in "real-world" tasks, it does not quantify the hand motions required. For a detailed analysis of EVA glove design requirements, a quantitative test protocol was recommended. This recommended protocol would include four phases: initial task analysis, baseline testing (gloved-hand motor and sensory capability), integrated or real-world performance evaluation, and experimental design and protocol. The initial task analysis phase would look at current EVA/EMU tasks and desired tasks which are not performed due to constraints imposed by the glove. Baseline testing would cover strength, range of motion (ROM) and fatigue measurements, an analysis of training effects on performance, sensory evaluation, and comfort. The third phase, integrated performance measurement, would involve evaluating performance of generic and specific EVA tasks with different gloves at various pressures. The experimental design and protocol evaluation would cover short- and long-duration glove wear, look at training programs, and develop a performance index for the glove tested. The recommended four-phase protocol strongly influenced the later EVA limitations study (EVALS) which is discussed later in this report.

A few other workshop proposals are noted here. A method was proposed for fatigue evaluation based on documenting performance versus time using the EVA schedule timeline as a basis. In-flight evaluations of task performance were also proposed. These evaluations concentrated on prehension, grasp, and dexterity. Specific fine and gross motor tasks would be performed by a suited astronaut so that glove/suit interactions could be evaluated. Other recommendations included studying the effect of astronaut hand training on performance and using a hand machine to study glove wear. The hand machine offers the advantage of allowing more exact measurements of "hand" position and applied forces/torques within the glove.

Two other glove designs are presented here. One is the MIT "skinsuit" glove. This glove, made either from a Spandex™ fiber or a natural rubber elastomer fiber, was designed to maintain a counter pressure against the skin to balance the pressure within the hand. By closely fitting the hand, without the need to maintain the pressurized volume, improvements in hand mobility, dexterity, and tactile sensing may be achieved.[18] The second glove design is a variable pressure glove incorporating some skinsuit-like features. In this design, a thin cover with a pressure pump covers the hand. Pressure can be varied to reduce resistance to hand motions.[19]

The gloves discussed in this section are only some of the varied designs looked at in developing EVA gloves. The glove prototype evaluated as a test of this protocol is briefly presented next.

D. Vanderbilt University EVA Glove Design

The Vanderbilt University glove (fig. 4) design approach has attempted to retain fuller use of the human hand. For this task, the human "dexterous hand" would be reenabled towards its original dexterity, while still being enclosed in the glove.

Figure 4. Vanderbilt glove prototype bladder and restraint.

The glove measures the force between the hand and the glove, and air bladders located on the back of the fingers inflate to maintain a constant force value between the hand and glove. This aids the fingers in overcoming stiffness due to pressure when flexing.[20 21] Currently, these finger bladders are located over the metacarpophalangeal (MCP) joints of the hand. A pressure sensor on the palmer face of the middle finger senses the force at the MCP joint between the hand and the glove. The signal from the sensor is used to inflate or exhaust the bladders. An alternate design uses springs in place of the bladders.[22 23] A picture of the glove bladder and restraint layer, without finger bladders, is shown in figure 4. The glove used in the tests described in section VI has a fabric restraint layer over a latex inner glove. It uses a fabric assembly to set the MCP joint neutral position at 0° in flexion.[22] This version of the glove does not use either the bladder or spring assemblies.

III. EVA GLOVE EVALUATION

A. Previous Studies

The Human Role in Space (THURIS) study found that it took 50 percent longer to do fine motor motions with the pressurized EVA gloved hand than the ungloved human hand. Coarse motor motions, however, took about the same length of time. The study suggested that the time difference in performing fine motor motions may be due to sensitivity and dexterity differences between the gloved and ungloved hand. These results were determined by comparison of EVA-suited versus self-contained underwater breathing apparatus (SCUBA) diver.[4]

The goals of the THURIS study were to investigate the role and amount of direct human involvement in future space missions, gain insight into the technological requirements and potential benefits of a human presence in space, and to establish criteria for allocating space tasks between humans and automation. To this end, the THURIS study broke down six mission types to the activity level. This produced 37 generic space activities. These activities are listed in appendix A. Of these 37 activities, 13 involve potential glove-hand motions.

The report "EVA Gloves: History, Status, and Recommendations for Future NASA Research," published in 1990, presents a combination of literature review and interviews with glove experts to provide a history of, and recommendations for, EVA glove research. EVA gloves were found to be one of the most critical components for EVA success.[10]

In this report, several power and precision grips are identified. According to the EVA gloves report, power grips rely at least on muscles in the forearm for strength, whereas precision grips primarily use hand and finger muscles. Figure 5 shows the three identified grips for each category. Common EVA hand motions identified by Lacey[10 24] are shown in figure 6.

Several recommendations are provided in the EVA gloves report. A few of these are presented here. The report recommends that EVA gloves, tools, and tasks be developed concurrently to help insure compatibility and performance flexibility. In addition, since the crewmember is the most adaptable component in the system, NASA should strive to provide as much natural hand capability as possible. The report also recommends that gloves be customized for each astronaut. This view was reflected by Joe Kosmo of NASA-JSC.[17]

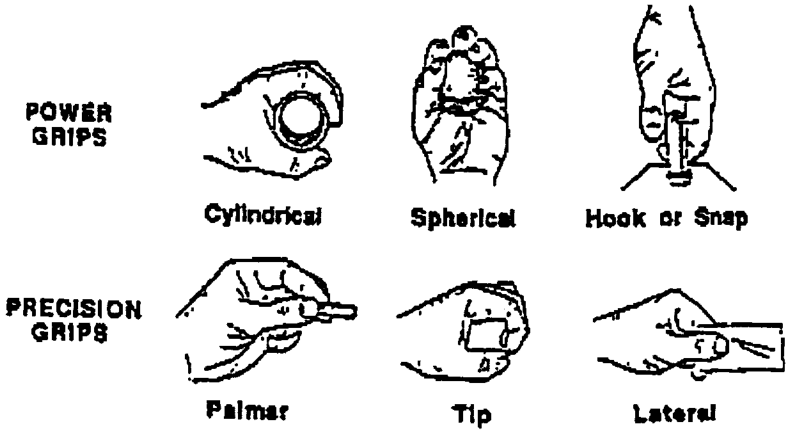


Figure 5. Types of grips.

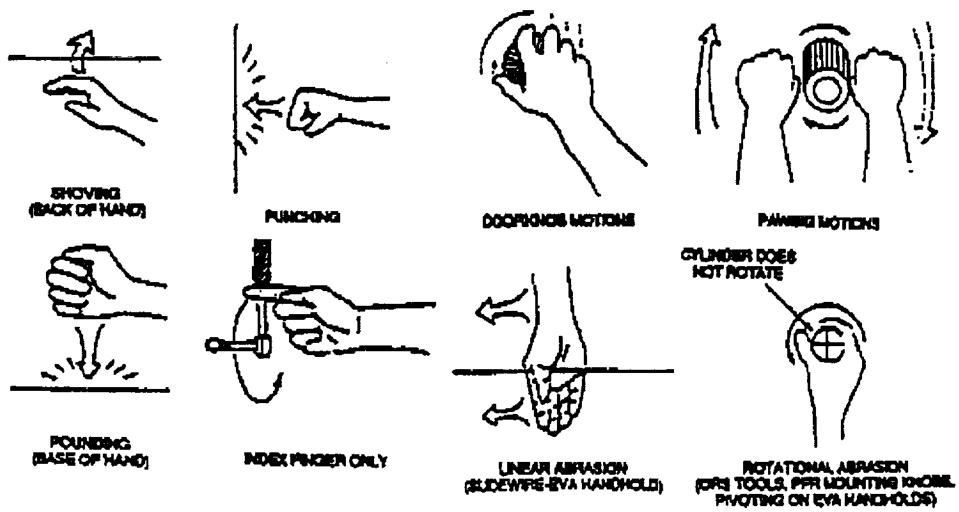


Figure 6. Common EVA hand and wrist motions.

Development of a standardized, quantitative battery of tests for EVA gloves was stressed. The report states: "The most important areas to be addressed in EVA glove testing are the development of quantitative performance tests and standards, enlargement of the EVA glove test bed, and the investigation of possible gender differences in EVA glove performance that could affect glove design."[10] Dexterity testing was seen as most important, closely followed by fatigue testing.

On the actual design of the glove box, the report indicated a need for a box with adjustable arm lengths, alternative gloves for the investigator, and flat surfaces to support video documentation.

The EVALS study (1988) is one of the most extensive studies of EVA glove evaluation to date. This study had two major goals: (1) to develop and evaluate a set of test methods designed to assess hand capabilities, and (2) to develop a data base of bare- and gloved-hand capabilities for a representative EVA glove.[25] To meet these goals, tests were designed to evaluate relative effects of EVA gloves, to examine differences due to pressure, and to determine the effect of hand size on basic hand capabilities.

Hand capabilities were broken down into six categories. Three of these categories (level 1) were based on performance capabilities directly related to hand anatomy and physiology. The other three categories (level 2) represented an integration of level 1 categories along with other factors. These capabilities, along with related parameters, are shown in figure 7, taken from the EVALS report.

Level	Capability Domain	Parameter
1	Range of Motion	Thumb Movement Finger Movement Wrist Movement
	Strength	Force (Pinch and Grip) Torque (Pinch and Grip)
	Tactile Perception	Continuous Sensitivity/Resolution Objects Characteristics Perception Tactile Feedback
2	Dexterity	Precise Positioning Two Object Manipulation Flexible Objection Manipulation
	Fatigue	Physiological Processes Subjective Manipulational Processes Performance Decay
	Comfort	Glove Characteristics Hand/Glove Interaction Local Hand Environment
3	Integrated Hand Performance	Real World Tasks

Figure 7. Hand capabilities.

Since "real-world" tasks may involve several of the above mentioned hand capabilities, these tasks were not emphasized in the study. However, the nine task components listed below were found to occur frequently in EVA missions.

- Using a power tool to drive bolts/screws
- Holding a handle or grip
- Mating or demating pins
- Tightening a latch with/without power
- Using a ratchet

- Tightening a tether
- Driving a gear with a ratchet motion
- Using pliers/wrenches, etc., for linkages
- Pulling and rotating switches, etc.

Eleven subjects were tested. Due to a lack of gloves in women's sizes, only one woman was included in the 11 subjects, so the data pertaining to her were not included in data analyzed for the report. None of the subjects in the EVALS study was expert in the use of EVA gloves.

Several recommendations were made in the EVALS report. Most of these were broken down by test category. Several are presented here. To aid in measuring ROM, a hand-support fixture was suggested to hold the hand in a correct orientation with respect to the video camera when videotaping ROM.

Designing the glove box and task to allow in-box measurements was also suggested. Finally, not knowing the actual location of the hand within the glove may have caused some lack of precision in measurements. This was also a factor in the two-point discrimination tactile test, as it caused some difficulty in determining where the finger actually contacted the edge.

For strength testing, a higher precision dynamometer than that used in this test was suggested. Knot-tying, nut-and-bolt, and pegboard tests gave similar dexterity results, so using just one of these tests (nut-and-bolt) was recommended.

In fatigue testing, the EMG measurements were found to be useful, although further study into electrode design and siting was recommended. Development of objective measures for comfort was also recommended.[25]

Where applicable, recommendations from these studies have been incorporated into the test protocol described in this report.

B. Basic Hand Capabilities

The wrist and hand contain 27 bones. Each finger is composed of three phalanges; the thumb has two phalanges and a metacarpal bone which forms its base. The other four metacarpals form the palm. The joints of the fingers are called interphalangeal joints (IP). The joint between the finger and palm is the metacarpophalangeal (MCP) joint. This joint is a ball-and-socket joint, allowing motion in several directions. The IP joints are hinge joints. The carpo-metacarpal (CMC) joint at the base of the thumb is a saddle joint.[10,26] Joints of the hand are shown in figure 8.

The human hand has over 25 degrees of freedom (DOF). However, many of these are coupled; for example, in bending of the finger joints, flexion of the distal interphalangeal joint is related to flexion of the proximal interphalangeal joint.[27] Object grasping is also a coordinated motion in which even the shape of the palm is modified to aid in the task.[28,29]

Additionally, the hand works in conjunction with the arm and even the whole body to produce a desired trajectory, grasp, or manipulation. This produces a kinematically redundant system, and causes effects beyond those which can be accounted for solely by end effector, hand controller, or even glove design.[30]

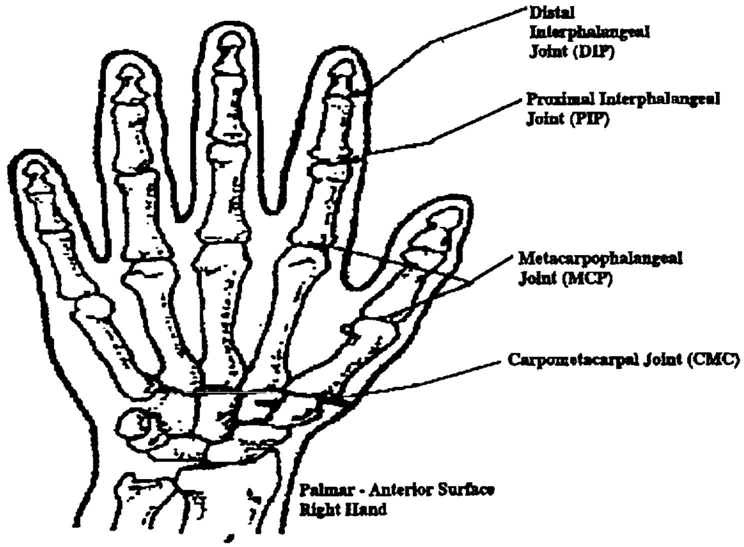


Figure 8. Joints of the hand.

Defining the range of motion of the joints of the hand is a complex process. In the field of prosthetic or robotic hand development, approaches to hand design have ranged from anthropomorphic to functional.[31–34] One anthropomorphic hand design has defined four 4 DOF fingers, a 4 DOF thumb, and 3 DOF for the wrist joint.[35] Another includes a "thumb nail" to aid in picking up objects from flat surfaces.[36] In most cases, the anthropomorphic and function-driven approaches have been combined. While a hand design may be somewhat anthropomorphic, it is driven by the need to complete a specific set of tasks. Usually this task set has been defined as grasping and manipulating an object.[37–40]

Hand dexterity combines the effects of range of motion, strength, and the hand control system which may be analytical (computer control) or organic (central nervous system).[5, 28] The musculature of the hand is designed for precise motions, with three to six muscle fibers per activating motor neuron. Other areas of the body may have 120 or more muscle fibers activated by a single motor neuron.[41] Vision, task difficulty and other factors will affect performance on tasks requiring high dexterity. Additionally, studies have indicated that the hand preshapes itself to aid in a particular task, especially tasks involving grasping.[25, 42] This may be to allow contact with the object at specific points in order to better adjust the grasp itself.[43] Using the palm as a restraint while performing delicate manipulations of an object is a technique often used by humans to assist in dexterity-intensive tasks.[44]

In grasping an object, the human hand uses information based on tactile sensing of the object. The amount of grip force applied is related, in part, to tactile sensing of the object to determine the security/stability of the grip.[28] Due in part to the lack of quick tactile sensing capability, vision has often been used as the only source for grasp information in robotic manipulator development.[45, 46] However, in glove testing at Vanderbilt University, several subjects noted that a lack of palmar tactile sensing capability caused difficulty in maintaining a grip. This has been borne out in other studies.[28, 29]

Tactile sensing itself is often accomplished by hand "exploratory" motions. Often a person uses specific motions designed to gain a particular type of information. For example, pressure was applied to assess an object's hardness, while enclosing and contour following were used to assess object shape and volume.[47]

Several factors may correlate with grip strength. Among these are weight and hand width. Height and mesomorphy may also play a role.[48] Hand strength really involves several types of strength. Cylindrical grip strength is used most often to determine a general level of hand strength.[5] However, aspects of overall hand strength include wrist strength, finger flexion, and extension strength as well as the strengths of other types of grips. The measurement of grip strength can be influenced by several factors, among these the subject's mental attitude, the time of day, and the amount of hand work performed prior to the grip measurement.[49]

IV. TEST PROTOCOL DEVELOPMENT

A. Test Methodology

Several EVA glove researchers have stated the need for a standard objective criteria for the evaluation of EVA gloves.[7,8,10,25,50] Such a criteria is helpful for glove to glove comparison, and "weeding out" nondesirable glove traits.[7] Ultimately, user acceptance will be the final selection criteria, however, objective performance criteria can be used to aid improvement of EVA glove designs.

One of the difficulties in defining gloved-hand performance has been getting an accurate measure of barehanded performance. If the goal of glove design, or at least a primary goal of glove design, is to reenable the gloved hand, then defining and measuring barehanded performance is important. Means of measuring barehanded capabilities are described in the section on experimental design.

One other goal of glove testing is to provide a way for glove and task designers to evaluate their progress early enough to modify a product in development. On occasion, when tools and gloves have been developed without communication between the designers, incompatible products have been developed and even baselined for use in the same mission.[51] Evaluation of a glove design or prototype against actual mission needs can be helpful during the development process, allowing individual glove characteristics, such as the ITMG, to be designed for a specific mission or set of missions. For this reason, a "real world" integrated task section was included in this glove evaluation protocol. The integrated task test section described in the next section is modifiable for the criteria being tested.

B. Purpose and Use of This Protocol

The purpose of this study was to develop a test protocol for evaluating EVA gloves. This protocol was designed to evaluate potential EVA glove candidates for use in particular EVA operations. EVA glove performance in specific areas may be compared to generate the best design for a specific mission, or an overall "better design" for projected NASA programs involving EVA.

Throughout this test series, barehanded performance is used as a baseline and reference measure. Test subjects are tested without gloves initially. If the candidate user population is known and accessible, it may be used in the tests to provide "natural" bare-hand performance as the baseline; otherwise, a sample "representative" population will be necessary for statistical analysis. Differences between this representative population and the actual user population are determined through comparison of hand measures (size, strength), familiarity with EVA gloves and systems, and other potentially relevant characteristics (age, sex).

One other use of this protocol is as a measure of the effects of hand training on the performance of the user population in gloved-hand tasks. It has been suggested that training the hands for improvements in characteristics such as strength could improve performance in EVA tasks.[7]

A diagram describing the use of this protocol is shown in figure 9. The user brings to the test series one or more glove candidates, a sample user population, and the type of mission to be performed. Results include a measure of the tested gloves' strengths for performing the stated missions, along with suggestions for glove design improvement.

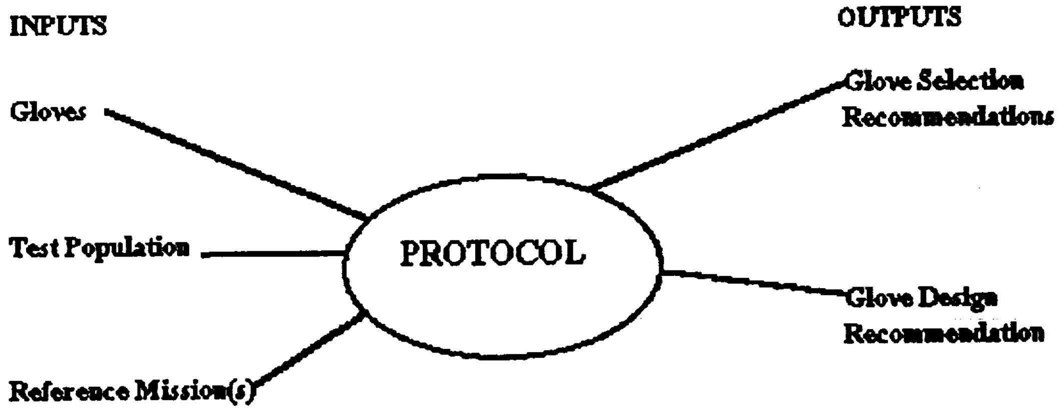


Figure 9. Test protocol.

With EVA gloves adjusted for each astronaut, the test protocol may be used to determine the best glove adjustments for the individual astronaut and the planned mission. Rather than using a test population of all EVA crew members, and expecting an output of recommended glove designs, the inputs to the protocol would be glove design so far, the individual astronaut (a test population of one), and the reference mission activities; the output would be recommended personal adjustments to the glove to aid the astronaut in accomplishing the stated mission objective. Using the protocol in this manner is meant to help the astronaut define the adjustments which best meet his or her needs. This is not intended to be used to define an entire glove design or major modification.

When a mature glove design is being evaluated for potential improvements, the modified glove's performance can be compared versus the unmodified glove's performance. The bare-handed performance case is still the baseline. Performance differences in the different test categories (strength, ROM, dexterity, tactility, comfort, integrated task) can be compared to see if the modifications improve performance in the expected areas. Differences between the gloved hand and the bare hand will show where the glove still restricts performance with respect to the ideal (ungloved) case.

C. Test Protocol Overview

This section provides an overview of the test protocol and its apparatus. A detailed description of the protocol is provided in section V, with the test series conducted at Vanderbilt University described in section VI. A glovebox, shown in figure 10, was developed for studying fine motor motions and dexterous tasks. The glovebox incorporated some of the recommendations of earlier studies.[10 25 50] The base and top were flat to allow for precise video documentation. The viewing glass was placed such that the video and task planes were parallel. A grid was affixed to the base of the glovebox. The measurements taken using this glovebox are divided into two groups; one for basic motion measurements and one for task-based measurements.

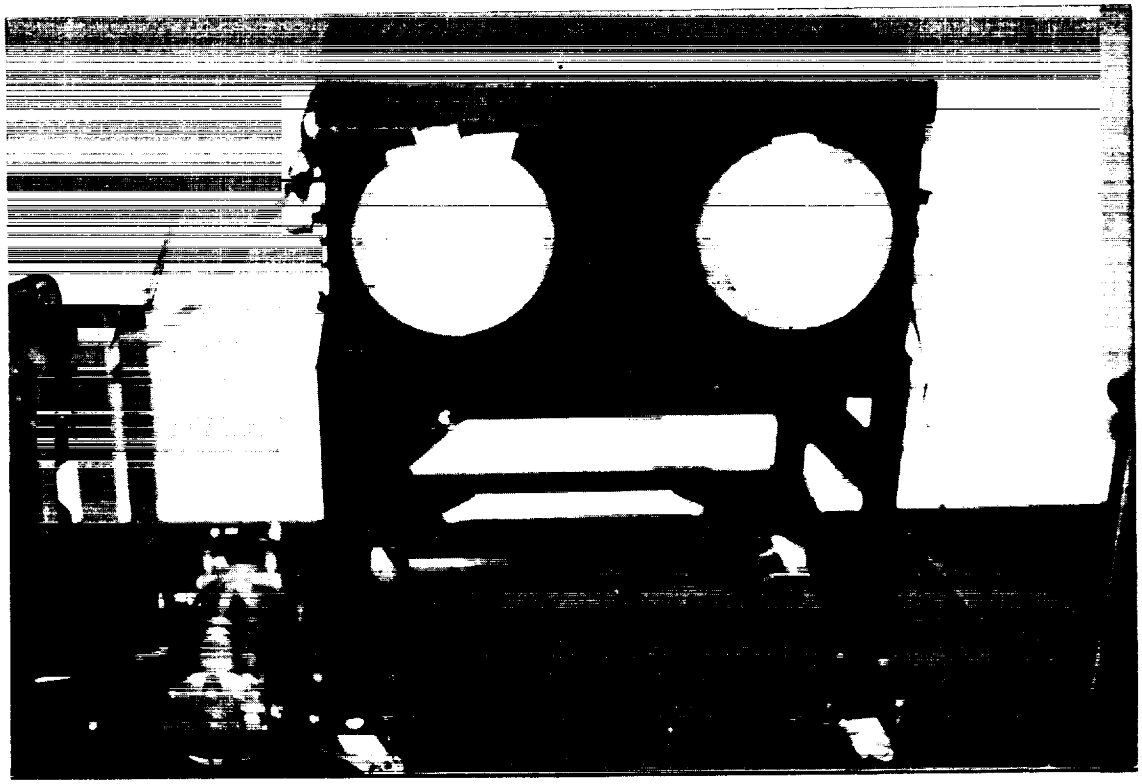


Figure 10. Glovebox.

Basic tasks concentrate on measuring forces applied to and by the gloved hand. These would include such things as ROM measurements, grip and finger strength, hand tactile sensing, dexterity assessment, and fatigue and discomfort induced by the use of a glove.

Task-based measurements are based on actual EVA mission needs. Some tasks rely on the hand alone, such as knob turning, and some tasks require the use of EVA tools. Most of these tasks are determined from potential EVA assembly and servicing missions. If the real mission needs are known, then the tasks and tools needed for that mission can be used in the integrated task portion of the test series.

Ideally, the test subject pool includes individuals of varying hand strength and size (especially covering the largest and smallest members of the group), both genders, and enough of each of these categories as required by different tests. In many cases, it will be difficult to assemble this group, requiring the researcher to try to accommodate as many criteria as are applicable and to define the variances between the research group and the actual user group. Naive test subjects, that is, those unfamiliar with EVA, may be especially useful when developing a glove which is radically different than currently used gloves, since the current users are likely to be biased to the design which they are used to. In cases where glove modifications for specific missions or mission categories (assembly, lunar/Mars) are being evaluated, an experienced test subject pool can provide more precise information on the modified gloves' applicability to the mission needs.

Section V presents the overall protocol design, including test apparatus, test presentation order, and a general discussion of statistical analysis and subject selection. Section VI describes the tests run on the glove prototype.

The remainder of this section discusses some of the issues which need to be determined when setting up a test using this protocol. These issues will vary depending on the test criteria; that is, if the test is being used to evaluate an early glove prototype with limited availability of test subjects, the test series will be set up differently than in the case of evaluating a modification to an existing glove with the final user population available as test subjects. In general, the major test factors are test subject availability and glove design readiness (prototype versus mature design). The test subjects may or may not be familiar with EVA operations. Test setups for combinations of these factors will be described in section V. The Vanderbilt University test series, described in section VI was done on an early glove prototype with limited subject availability. The Vanderbilt University subjects were unfamiliar with EVA operations.

The first step in using this protocol is defining the desired output. This may be design enhancements or directions for the design process to take, or an evaluation of a flight-ready glove may be desired. From here it is necessary to determine how many sizes of the glove are available and the availability of test subjects. In evaluating a flight-ready glove, it is likely that experienced EVA astronauts will make up the test subject population. In this case, while valuable personal insights will be gained during the test process, an objective assessment of the glove's performance will also be provided by the protocol. Once the number of glove sizes and test subjects are known, determining the number and population of test cells can begin. Subjects are classified by hand strength and size (if more than one size of glove is available). Grip strength is used as the measure of hand strength. If four glove status (GS) conditions (no glove, 0 psid, 4.3 psid, and 8 or 8.3 psid) are being evaluated, such as in the case of comparing a glove design's performance with respect to pressure effects, multiples of four (subjects) will be needed to fill the test cells. If a 4.3-psi glove is being tested, the GS conditions will be no glove, 0 psid, and 4.3 psid, and multiples of three subjects will populate the cells. The glove is always compared to the bare hand. Performing the test with the unpressurized glove also allows some determination of pressure versus fabric effects. Since subjects will perform the same set of tasks in all of the GS conditions, it is important to randomize the GS presentation order to counteract learning effects. This process is presented in greater detail in the next section.

Determination of which, if any, of the integrated task tests to use is driven by the mission needs. Possibly a specific tool will be used, or some particular hand motions will be repeated. If a long duration of sustained fine hand motions is planned, the "busy box" task could be selected. Although the glove fit comfort questionnaires are placed at the ends of the dexterity and fatigue segments of the test series, it may be useful to place the first questionnaire after the integrated task rather than the dexterity test in certain cases.

V. PROTOCOL DESIGN

A. Parameter Classification

In developing this protocol, reenabling bare-handed capability was assumed to be the primary concern of glove development. It may be useful someday to enhance the hand's basic capabilities, but most EVA glove development to date has concentrated on emulating or recreating "shirt-sleeve" environment capabilities. This criteria is relevant to most environment-suit gloves, and even some robotic manipulators. Therefore, tests were devised to evaluate gloved-hand performance, including pressurized and unpressurized gloves or glove states and bare-handed performance on the same set of tasks. These tests covered the areas of ROM, strength, tactile sensing, dexterity, fatigue, and comfort. These categories reflect those used in the EVALS study.[50] Other category divisions were examined, however, these were felt to best describe and differentiate hand capabilities. A mission-based "real world" task evaluation is also provided for in the test protocol. This test can be used to provide information relevant to a particular mission criteria.

The tasks are performed within a pressure-sealed glove box. The tasks are done bare-handed, wearing a glove at 0 psi, wearing a glove at 4.3 psi (current EMU suit pressure), and, if a higher pressure glove design is being tested, wearing a glove at 8 (or higher) psi. The 8 psi condition is included to cover projected EVA suit designs which operate at this pressure. Testing at 0, 4.3, and 8 psi will aid in differentiating glove design/fit effects and pressure effects. (If the necessary ROM, strength, tactile sensing, and dexterity required for a task is known—and it is within the range of the glove box testing capability—it may be possible to test and compare manipulator performance using this glove box.)

B. Test Subject Selection

The independent variables for the test series are GS, hand strength, and hand size. GS is the subject wearing no glove, wearing the glove while it is unpressurized, and wearing the glove fully pressurized to either 4.3 or 8 psi. Each subject tests with each of these conditions.

It was determined that the most likely differentiators of performance in using the glove would be the operator's hand strength and hand size. Both hand strength and size are conditions specific to an individual's hand which could affect that individual's performance of a task. Strength varies between operators in the grip and finger strength glove tests. Hand size affects range of motion (ROM), and possibly dexterity, results between operators. Because of this, subjects selected for this test series are classified by hand size and strength.

The NASA Standard 3000 (p. 3–13) gives the following breakdown for defining hand size.[13]

	HAND LENGTH	BREADTH	CIRCUMFERENCE
5th percentile	15.8 cm (6.2 in)	6.9 cm (2.7 in)	16.5 cm (6.5 in)
50th percentile	17.2 cm (6.8 in)	7.8 cm (3.1 in)	17.9 cm (7.0 in)
95th percentile	18.7 cm (7.3 in)	8.6 cm (3.4 in)	19.3 cm (7.6 in)

Initial test subject screening can be based on these values. However, in prescreening for testing at Vanderbilt University, most hands, whether men's or women's, fit into the medium or large categories. These values are median values, and do not cover the entire percentile range.

The charts in figures 11 and 12 from the NASA Standard 3000 show the relative grip strengths for men and women. The population for males was composed of U.S. Air Force air crewmen; the population for females is presented in two groups: U.S. Navy personnel, and U.S. industrial workers.[13]

Population	Percentiles			
U.S. Air Force Personnel, air crewmen	5th	50th	95th	S.D.
Right Hand	467 (105)	596 (134)	729 (164)	80.1 (18.0)
Left Hand	427 (96)	552 (124)	685 (154)	71.2 (16.0)
Strength in N (lb)				

Figure 11. Grip strength for males.

Population	Percentiles			
U.S. Navy Personnel	5th	50th	95th	S.D.
Means of Both Hands	258 (58)	325 (73)	387 (87)	39.1 (8.8)
U.S. Industrial Workers Preferred Hand	254 (57)	329 (74)	405 (91)	45.8 (10.3)
Strength in N (lb)				

Figure 12. Grip strength for females.

Clearly, strength varies between men and women. However, with pretesting for hand strength and size, these differences will be reflected in the distribution of the test subjects within test cells: for instance, more women located in the small/weak hand cell, while more men will occupy the large/strong category. Additionally, due to the protocol design, subjects are being evaluated between the different GS conditions (within-subject), rather than against each other (between-subject). This provides information on how a pressure glove affects performance based on hand physiology.

The next several paragraphs describe a test setup for an 8 psi glove evaluation when several sizes of the same glove are available, along with a large enough pool of test subjects; in short—ideal conditions. In cases where the number of test subjects is limited, the availability of gloves is limited, or a subset of manipulation capabilities is being tested, a reduced version of this protocol may be performed. The test series described in section VI is one of these cases.

To determine the subject pool, pretesting for hand size and strength is done. Hand size is broken into three categories, small, medium, and large. Hand strength is categorized as high or low. Hand strength category may be determined by using grip strength, as this is a commonly used indicator of overall hand strength.[52] This combination produces a 3 by 2 array to be filled, as shown in figure 13.

Each subject in a given cell (such as medium or strong) will test in each GS condition (no glove (NG), wearing glove at 0 psi (0PSI), wearing glove at 4.3 psi (4.3PSI), and wearing glove at 8 psi (8PSI)). A minimum of four subjects should be chosen for each cell, although more are acceptable.

Choosing four subjects per cell allows the presentation order of the GS conditions to be varied such that no two GS conditions are always presented in the same sequence. This is done to control learning effects[53 54].

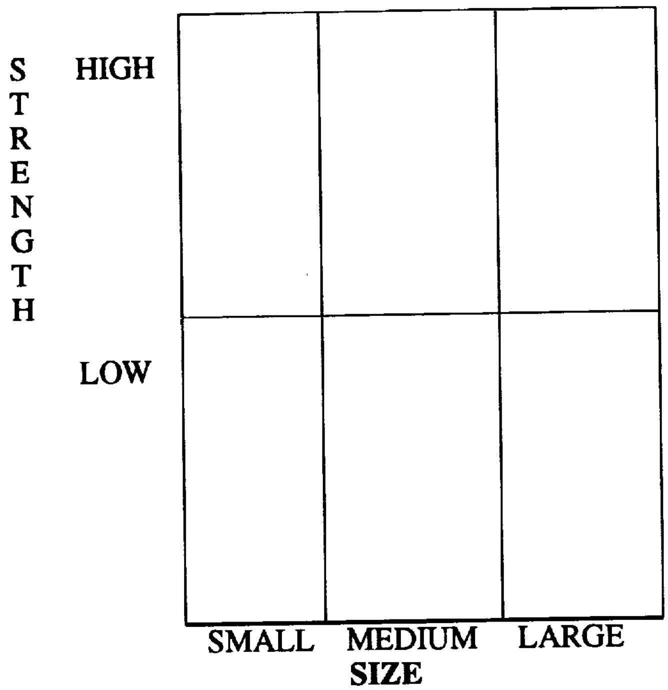


Figure 13. Hand classification array.

Allowing t to be the number of GS test conditions, it can be seen that there are 24 ($t!$) possible sequences in which the GS test conditions can be taken. In order to control any sequence order effect—such as one GS condition always following another, thereby influencing the subsequent test results—n sequences (where n is the number of subjects per cell) are chosen at random. Subjects within each cell will be randomly assigned to each sequence with no sequences repeated within a cell.

A field of 36 subjects would allow for complete counterbalancing using a full Latin square to assign test sequences to subjects, however this may be impractical since six subjects must then be found per cell. In addition, test setup time increases dramatically. Time to evacuate the glovebox between tests, plus sufficient rest time for each subject between trials, must be allowed for in the test series. This has to be coordinated with subject scheduling and availability. The method described above, with at least four subjects per cell, provides sufficient counterbalancing to compensate for sequence order effects.[53]

A test subject's results are compared between that individual's performance in each GS to indicate increase or decrease in performance in each of the testing areas. Although comparisons may be made between the performance of different test subjects, primary concentration is placed on determining improvement or degradation of the gloved-hand performance due to glove design. Some comparison can be done between subjects to drive out effects due to hand size and strength.

To do both fatigue tests, an extra day of testing is needed, since the two fatigue tests cannot follow each other—or even be in the same test sequence—without affecting each other.

In the case where a glove with an operating pressure of 4.3 psi is being tested, there would be three GS conditions: NG, 0PSI, and 4.3PSI. A minimum of three subjects would then be chosen per cell, producing a total of 18 test subjects.

If two sizes of hands were used, only four cells would need to be populated. In the test series presented in section VI, there was only one size glove available, so subjects' hand size was set by the glove size. In this case, only two cells were necessary: high strength and low strength. Similar reduced test configurations would be produced when testing a design prototype to determine future design directions.

In testing a pressure glove, at least three GS conditions will be necessary, with one being the operating pressure of the glove, and the other two being NG and 0PSI. This will allow comparisons of effects due to the fabric work versus the effects due to pressure work.

C. Test Description

The variables tested for, and the test(s) used for each, are listed in figure 14. A more complete description of tests is given in the next section. The dependent variable is measured quantity used to indicate performance in a particular test. For example, in the ROM tests, the measurements are the angles through which the fingers and thumb can move in degrees. In the case of dexterity, the measure is how many times the task is completed in a given amount of time.

DEPENDENT VARIABLE	TEST
RANGE OF MOTION (degrees)	Videotape FINGER and WRIST motion against a grid. Do same for THUMB.
STRENGTH (force)	Measure GRIP, and WRIST YAW, PITCH, and ROLL. Measure FINGER (digits 2 and 3) extension strength. Measure pinch grip of first finger with thumb.
TACTILE (cm. & object identification)	Determine where FINGERTIPS lose differentiation between two diverging surfaces.
DEXTERITY (# of cycles)	Do NUT and BOLT task. Pick up nut and bolt in specified orientations and put together. May do once **with** VISION, once **without**.
INTEGRATED (success & time)	Test and mission criteria dependent.
FATIGUE (Temp & Hz, delta force)	**Do last**. Squeeze a dynamometer and flex and contract hand. Measure performance degradation on a gripping task.
COMFORT	QUESTIONNAIRE <u>after</u> Dexterity and dynamic-work Fatigue test series.

Figure 14. Tests and dependent variables.

The with and without vision dexterity tests are run first with the subject viewing the task, then without for each subject. Subject performance is compared between test conditions, not between the viewing and nonviewing run. If dexterity performance is already significantly impaired by use of the glove, it would not be useful to include the nonviewing run as little extra information could be gained.

The glovebox built for these tests has a flat top for photographing or videotaping hand activities while looking straight down on the task. The flat base of the box allowed a grid to be placed beneath the task site while videotaping. A port for a second glove was provided for the test conductor to arrange test articles and provide support during the task. More discussion of this glovebox is provided in the glove test series section of this report.

D. Tasks

1. Range of Motion. ROM is measured by videotaping the motions of the hand, thumb, and fingers, and calculating the angles through which the joints move. To do this, a Cartesian grid is affixed as a background within the glove box with respect to the direction of the camera view. The subject is asked to move the joint through its full ROM. The motions measured are:

Metacarpophalangeal (MCP "knuckle" joint) joint flexion for all fingers, and separately for the second and third digits,

Proximal interphalangeal (first joint past knuckle) flexion for thumb, second and third digits, other digits, and all four fingers,

Thumb carpometacarpal (CMC) extension, opposition,

Wrist flexion and radial extension (pitch),

Wrist ulnar and petal deviation (yaw).

If the neutral position of the gloved-hand is known, finger extension from that position may also be measured. Alternately, extension of all fingers together may be measured. This type of measurement may be especially useful when attempting to determine the influence of pressure effects on ROM. These tests are done in the same order for each of the subjects.

Thumb CMC joint produces a three-axis motion.[25] Thumb opposition and the maximum possible inplane angle between the thumb and the fingers were used to determine glove restrictions on thumb ROM. These motions were used due to the availability of glove and anatomical landmarks from which to take measurements, and to provide at least two points and which the glove's effect on thumb motion could be measured.

Wrist roll combines a full forearm motion, making glove design effects on wrist motions difficult to measure. Measurements of wrist roll can be taken, although their reliability in quantitative glove evaluation and comparison remains to be determined.

2. Strength. A dynamometer is used for measuring grip strength. A pinch dynamometer is used to measure pinching strength.

Extension strength in the thumb and first two fingers is measured. The hand will be set in a hand rest while the finger extends against a restraining force.

As in ROM testing, wrist roll is a full forearm motion, and as such combines effects beyond that of glove design which are difficult to separate out in glovebox testing. Strength measurements of wrist roll are not performed.

3. Tactile. The two-point aesthesiometer test is often used to test tactile sensing, and a subject's ability to distinguish two separate sources of skin contact. This test usually involves touching the test subject's skin with two closely spaced needles. To compensate for glove thickness, previous studies have used two diverging surfaces as shown in figure 15.[25, 51] This test is performed as it allows some comparison with previous testing and is fairly easy to calibrate. Multiple trials are done per subject, randomly varying the separation of the surfaces from no gap to a 1.5-cm maximum gap size at the end. Tests may be done without viewing the test article to keep the subject from "guessing" the point of divergence based on knowing the gap size.

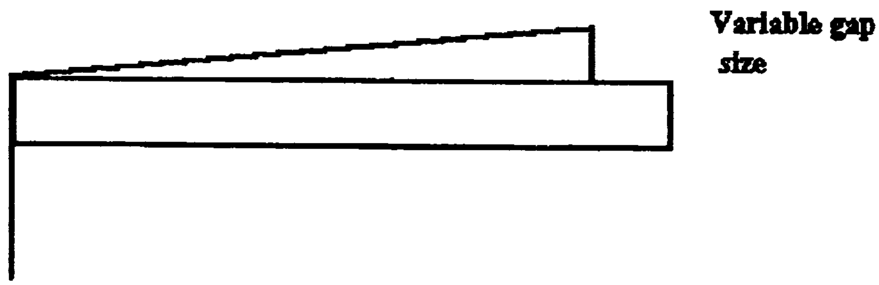


Figure 15. Diverging surfaces tactility tests.

4. Dexterity. The dexterity test is a bolt insertion task. Bolts are picked up from a tray and threaded into a board for approximately five turns. The subject is asked to work for 1 min, and the number of bolts inserted is recorded at 15, 30, and 60 s. Drops are recorded as errors. This test allows for dexterity assessment when only one glove is available. Two bolt sizes are used, 1-in length by $^{5}/_{16}$-in diameter, and 1-$^{1}/_{2}$-in length by $^{1}/_{2}$-in diameter. Each subject inserts bolts of both sizes; that is, each does one trial per size. This may be affected by the dexterity allowed by the glove; in some cases, subjects may not be able to manipulate the smaller bolts. To require additional precision in hand positioning, the bolts can be arranged on two orthogonal surfaces. Subjects are then required to alternate between these surfaces in removing bolts. This was not done in testing the Vanderbilt University prototype for reasons discussed later. Smaller assemblies can also be used to study gloves allowing higher finger dexterity as was done by Dr. Manley Carter in his tests.[55]

The peg-bolt test can be repeated with the subject unable to see the task. This is done to represent the manipulation required on an obstructed-view task. Each subject does the task first with vision, since in many astronaut EVA tasks, the task has been simulated beforehand.

5. Integrated Tasks. Astronauts on missions have sometimes been asked to perform "busy box" tasks to drive out EVA gloved hand performance.[55] A "busy box" has a set of basic tasks, such as flipping a switch or plugging/unplugging a cable, which are repeated during the course of the test. The best predictors of future EVA performance would seem to be actual EVA tasks. These tasks are included to attempt to simulate some of the potential "real-world" tasks a gloved crewmember may have to perform. Often these tasks combine several hand functions and performance parameters.

The integrated task design is the test most directly affected by mission criteria. While one integrated task may provide information for a given mission criteria, another might be better for evaluating the glove against a different mission. For example, in testing the Vanderbilt glove prototype, the first series of tests was geared toward evaluating the glove's ability to aid finger motions, since wrist capabilities were not yet provided for. A ratchet task would not be the most suitable in this case due to the extensive wrist motion required, however, a task using a tool with a finger release does provide significant useful information on finger joint design. In the case of long duration missions where a glove's performance in all six categories is important over a period of time, the integrated task might be a series of representative tasks requiring several hand motions repeated over a longer time period. This is similar to the work J. Kosmo and A. Ross were doing at JSC.[56] In their project, they asked astronauts to perform several "busy box" tasks for extended time periods. Some of the tasks required tool use, while others, such as flipping a switch, did not.

Several integrated tasks are described below. Each of these may have special application to a particular mission scenario. The integrated task test series should be set up by comparing the mission profile and the tasks listed below.

Trigger tool tasks test the ability of fingers to operate individually and in concert with each other in order to activate the tool. The tool handle is grasped by the thumb and third through fifth digits, while the trigger is activated by the second. Some power tools use a trigger bar rather than a smaller "button." Even so, this just causes another digit or so to be used in applying pressure to the trigger, while still requiring the coordination of this finger motion with the gripping action provided by the thumb and remaining digits. This test is useful for examining glove restrictions on dexterity and finger strength.

Tools with a finger release, such as the needle-nose pliers used in the Vanderbilt University tests, provide information about independent finger dexterity, especially as digits four and five can operate together to release the tool, while the whole hand is used to grip the tool closed. Operating pliers and or wrenches requires grip strength and a suitable ROM for finger/palm flexion and extension.

Grasping an EVA handhold while moving the body along a desired trajectory requires grip strength, wrist strength, and wrist/forearm ROM suitable to maneuver the payload. T-handle tool grips require some finger flexibility, and potentially some wrist strength.

Tether attaching and tightening requires finger dexterity, wrist/forearm strength and ROM, and some grip strength.

Ratchet tool tasks require the wrist and forearm to move in an arc while constant force is maintained on the ratchet head. Maintaining grip while performing this action is important.

Plugging in and unplugging a cable requires finger dexterity and strength, finger and palm ROM which allows for a collet style grip, and possibly some wrist roll depending on the type of cable or whether the cable needs to be "jiggled" loose.

Long-duration "busy box" tasks may require several distinct coordinated hand motions repeated over time. This test will also show where glove chafing or pinching may occur over time.

6. Fatigue. An objective measure of the onset and progress of muscle fatigue can be provided by recording electromyographic (EMG) signals from muscle groups of interest. The frequency change in an EMG signal can be measured to give an indication of physiological condition of the muscle. EMG data

can be gathered during a sustained muscle contraction, and the reduction of the median frequency can be measured. Comparisons may be made during contractions done at different times during a test. To evaluate performance decay, work done against a restraining force may be measured over the course of the test. This is the methodology used in the EVALS study.[25 50]

Task performance decay may be used as a measure of fatigue as well. In this case, the subject is asked to repeatedly grip a dynamometer, applying as much force as possible at specific time intervals. The time until the subject produced a given fraction of their maximum contraction force provides a measure of fatigue induced by dynamic work. Fatigue induced by static work (i.e., continued gripping at a given force level) requires another measurement. The advantage of this test over EMG measurements is its lower cost, however, it is more subjective as it is based solely on the subject's performance over time rather than incorporating a specific measurement. Task performance decay was the only test used in this protocol. There was no room to seat electrodes once a good glove fit to the hand was achieved.

7. Comfort. A questionnaire is used for comfort testing. The Glove Fit Questionnaire asks subjects to pinpoint, on a picture of a hand, areas which have experienced contact with the glove. Subjects are asked to describe the nature of the contact—for example, light to heavy contact (touching), pressure points, chafing, or pinching—and the degree of discomfort induced by each contact. These scales were drawn from the ILC and Grumman comfort scales. The questionnaire combined features of the astronaut glove fit check chart and a fit and comfort chart used in JSC glove studies.[10 56] This questionnaire is given at the end of the dexterity and fatigue tests, respectively.

One potential problem with this method is the possibility of blisters or other discomfort being induced midway through the overall test series. To avoid this, each subject is asked to describe his hand condition before testing in each GS condition by filling out a Hand Comfort Questionnaire. The questionnaire asks subjects to state whether any hand discomfort noted would affect their ability to perform in the current test session. Both questionnaires are given in appendix B.

VI. GLOVE TEST SERIES

A. Test Program

This section describes the test series used to evaluate a glove prototype. The primary purpose of this test series, however, was to determine the effectiveness of the test protocol for a real case. In this, the tests were generally successful. Most measures provided relevant data about the glove design, while a few indicated room for refinement of the protocol.

The full test series associated with determining a glove usability measure for a given mission has been described in section V. In the case of this glove prototype, it was known in advance that the glove had certain limitations. Therefore, the test series was adapted to cover testing of the glove's features, without testing nonexistent features.

The glove prototype was primarily designed with an eye toward improving finger capability. At the time of testing, there was no wrist joint on the glove. In addition, there was only one size of glove, limiting the hand sizes that could be tested. The finger control system was not yet implemented, so a basic glove, without the finger control enhancements, was used in running the test series.

In terms of the test protocol, the inputs and mission criteria were as follows. The test series would be done for one glove candidate; the sample population would be primarily Vanderbilt University students (due to their availability); and the mission criterion was examining the ability of the glove design to reenable finger capability. The desired outputs were an evaluation of the glove's performance with respect to finger/palm capability and suggested improvements to the glove design in this area. An additional desired output of this test series was an evaluation of this test protocol as a means of producing the stated outputs. From this, extrapolations would be made as to the effectiveness of this protocol in a more expanded test.

Potential test subjects were "interviewed" for the series several days before actual testing began. Their hands were measured for length, palm breadth, and palm circumference. This would provide a reference to the NASA 3000.[13] Additionally, the students were asked to commit to the duration of the test series to avoid losing candidates in any one test cell during the test.

Hands were divided into two categories by strength. The initial test design was set up for evaluating two categories of subjects in four GS conditions. This meant that eight subjects were necessary to cover all GS conditions in each hand category. To eliminate placement order effects, subjects were randomly assigned to GS presentation order without replacement.[57 58]

Grip strength was measured during pretesting to determine placement in the "high" or "low" strength categories. This determination was based on measurements from previous tests, and the strengths available in the test population. A total of 26 people was pretested. One of the major factors limiting subject selection was the size of the glove. Many hands measured were too large to fit the glove.

The final subject pool included six males and two females. None of the subjects had experience with pressure gloves. All subjects were right handed. None of the test subjects had apparent injuries or abnormalities which would affect the functioning of the right hand. A comparison of this population and the potential glove user population (EVA astronauts) is provided here.

In relating the test subject population to the actual glove user population, variations in physical characteristics should be assessed with respect to the NASA standard crew norm. The NASA Standard 3000 used a crew member age of 40 years at an operational year of 2000 when developing their crew "norm" characteristics.[13] The subjects tested ranged in age from 20 to 39 years. The standard secular growth rate per decade for the American male (95th percentile) is 1.0 cm, and 2.6 cm for the Japanese female (5th percentile). Given the ages of the subjects, these figures would put them within a decade of the NASA crew member norms.

In assessing grip strength variations, age does have an effect. However, age related effects are fairly constant between the ages of 20 and 42 years as shown by figure 16. This range encompasses the subjects ages. The values shown in figure 16 are based on averages of right and left hand strengths.[48]

Figure 17 shows the strength measurements and ages for the test subjects. The three strength trials, J1, J2, and J3 were averaged. Values are in pounds. Subjects were allowed to choose the grip dynamometer setting (J-setting) which produced the highest results for their grip strength trials. Test sequence refers to the presentation order of the GS condition as shown in figure 18.

AVERAGE GRIP - Strength vs. Age

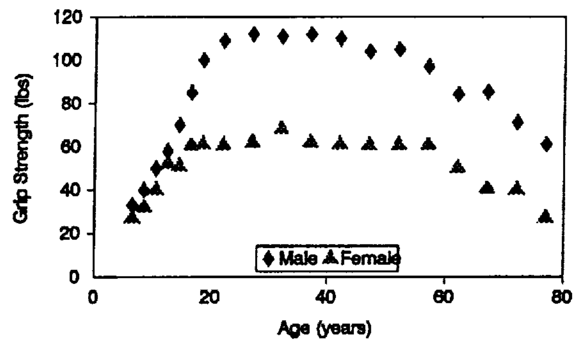


Figure 16. Hand strength (average of right and left hands).

Subject No.	J-Setting	Strength Measurements (lbs) J1	J2	J3	Average	Cell [Hi, Lo]	Age	Test Sequence [ ]
1	2	54.0	51.0	53.0	52.7	ST	20	4
5	2	39.0	39.0	39.0	39.0	WK	20	2
6	1	38.0	38.0	34.0	35.7	WK	23	3
9	1	48.0	48.0	53.0	49.7	ST	24	3
11	1	60.0	50.0	52.0	54.0	ST	22	2
12	1	39.0	32.0	32.0	34.3	WK	39	1
13	1	62.0	57.5	54.0	57.8	ST	23	1
15	2	18.0	21.0	18.0	19.0	WK	20	4

Figure 17. Subject information.

Glove Status	No.	Sequence	[1]	[2]	[3]	[4]
Bare	1	GS	1	2	3	4
0PSI	2	GS	2	3	4	1
4.3PSI	3	GS	4	1	2	3
8.0PSI	4	GS	3	4	1	2

Figure 18. GS presentation order.

The tests performed are described below. Before testing in any GS condition, the subject was asked to fill out a hand comfort questionnaire. This questionnaire asked that any significant hand discomfort be noted and identified on a picture of the hand. The hand pictures in this and the Glove Fit Questionnaire were identical to allow some standardization of test subjects' responses. The subject was also asked if any noted discomfort would preclude testing in the current session's GS condition. This questionnaire can be found in appendix B.

All subjects performed all tests in each GS condition. Tests were always performed in the same order during a test session. The fatigue test was always performed last in any test session.

ROM was measured for bending of all fingers together at the MCP joint, bending of digits two and three individually at the MCP joint, and motion of the thumb at the carpo-metacarpal (CMC) joint.

Hands were visually aligned against a background grid, then videotaped as they performed the ROM exercises. ROM was measured from the glove aligned along a grid line parallel to the forearm to full flexion. Figure 19 shows a typical MCP flexion in the pressurized glove, however, the video was taken with the hand perpendicular to the background grid rather than at an angle as shown in the picture.

Figure 19. Range of Motion testing.

The next test in the series was the grip strength test. Five trials were performed, during which the subject was asked to squeeze a dynamometer with maximum contraction. The dynamometer was adjustable, allowing the person using it to set it to one of five settings.[48] During pretesting, each subject was asked to set the dynamometer to whichever setting was most comfortable for gripping. They were allowed to work with the instrument until a setting for which maximum strength was produced could be found. This was done to account for mechanical advantage differences between hands of different sizes. During their test runs, each subject used the dynamometer at the same setting as they used in pretesting. The hydraulic grip dynamometer is shown in figure 20.

The third test was the pinch test. For this test a key pinch, thumb to side of the second digit as in using a key, was used. An hydraulic pinch dynamometer, shown in figure 21, was used for these tests. The instrument was designed for its weight to be supported by the therapist rather than the person taking the pinch test.[59] The pinch gauge was supported by a test stand during all pinch tests.

The next test was the finger extension test. This test was developed to look at glove effects on finger extension. From early childhood, the hand tries to grip objects. Extension of the fingers, especially against a restraining force, such as a pressurized glove might provide, is performed less often.[8] It could, however, affect performance on some EVA tasks, especially in manipulation of tools requiring some independent finger motion. Certain grasping motions, especially when vision is restricted, involve first extending the palm and fingers.[16] For this test, the dynamometer was positioned so the hand was level underneath it. Subjects were asked to use just their finger (digit 2) and attempt to lift it against the dynamometer. Figure 22 shows the test stand for this test.

The next test evaluated fingertip tactile sensing using a diverging surfaces test apparatus as shown in figure 23.

Figure 20. Grip dynamometer.

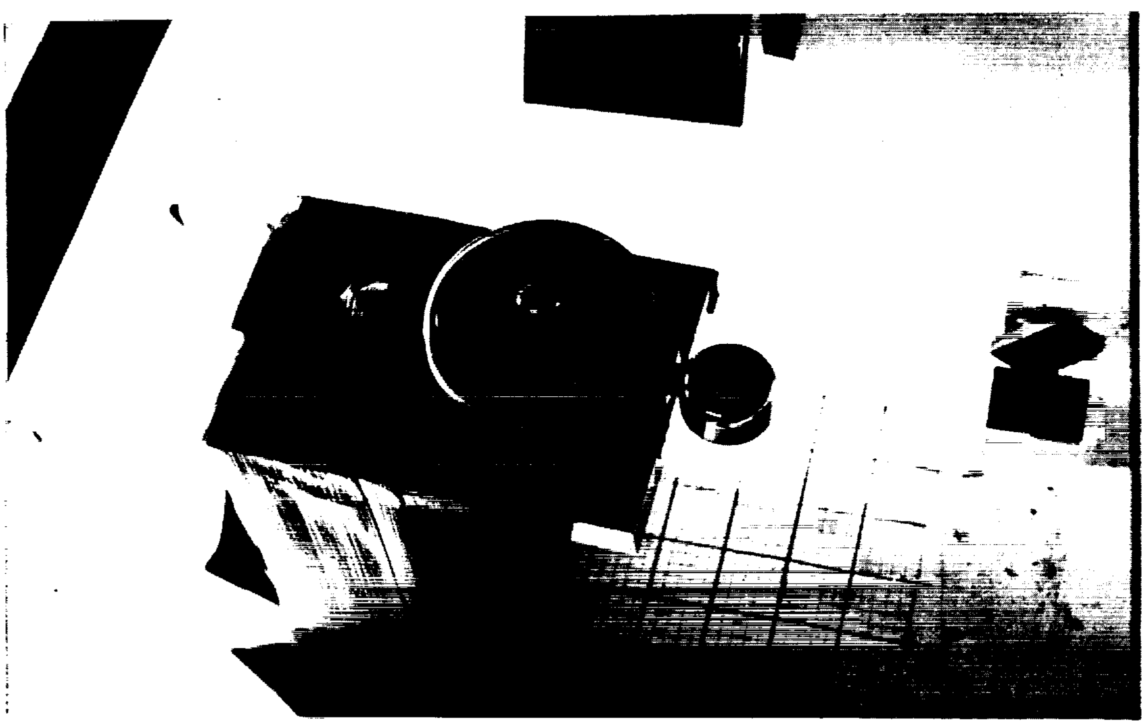


Figure 21. Pinch dynamometer on test stand.

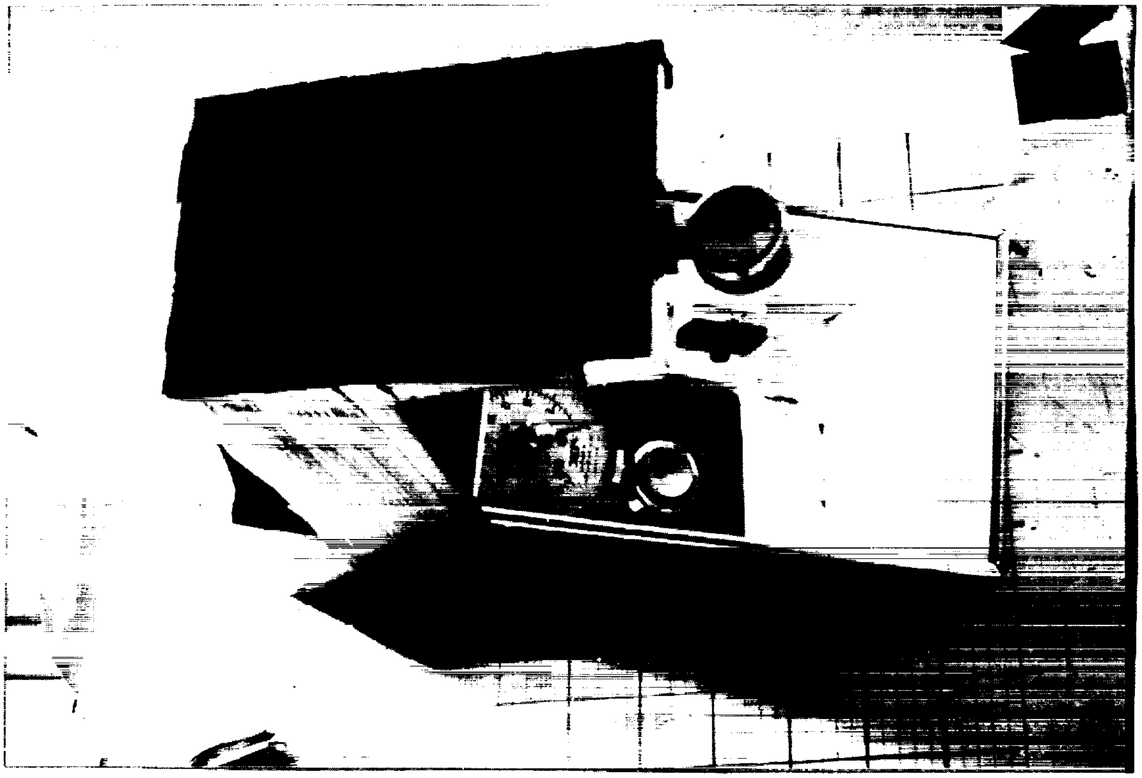


Figure 22. Finger extension test stand and dynamometer.

Figure 23. Tactile test using diverging surfaces.

The surfaces start together, and diverge to a preset gap at the end. The gap between the two surfaces was varied. During testing, three settings were used; the gap was set at either 0.5 cm, 1.0 cm, or 1.5 cm. These settings were presented randomly to the subjects.

A peg-bolt task was used in evaluating dexterity. The subjects were asked to insert a bolt into a threaded hole on a plate. Any hole on the plate was acceptable, and the bolt only needed to be threaded enough to stay inserted. Tests were originally tried with two sizes of bolts, 1/2-in and No. 10, however, with the glove pressurized, only the largest bolts were able to be manipulated. A tray with fifteen bolts was placed near the back plate to minimize wrist or forearm motions to pick up bolts. The number of bolts inserted at 15, 30, and 60 s was recorded. Dropped bolts were recorded as errors. Only one base plate was used, rather than two orthogonal plates, due to the restricted wrist capability. This test setup is shown in figure 24.

Figure 24. Dexterity peg-bolt test.

The first was to ask the subject to open and close an EVA tether tool. The EVA tether tool was selected because it required coordinated finger motion to depress both releases, along with a finger/palm grip motion to open the hook. Tethers using this type of mechanism are used on all orbiter EVA's, making this a common task for an EVA gloved hand.[60] The second task was opening and closing needle nose pliers. This task required use of the fingers to release the mechanism. The pliers were also an EVA tool, however, the EVA version of this tool is based on the off-the-shelf tool, so its operation was somewhat more familiar to the test subjects. Subjects were not experienced with EVA tools. These tools are shown in figures 25 and 26.

A dynamometer-based fatigue test was used to measure differences in work induced fatigue due to glove use or pressurized glove use. Subjects were asked to squeeze the grip dynamometer to maximum contraction while maintaining a set pace. Measurements were taken when contraction forces were at one-fourth and one-half of their maximum levels.

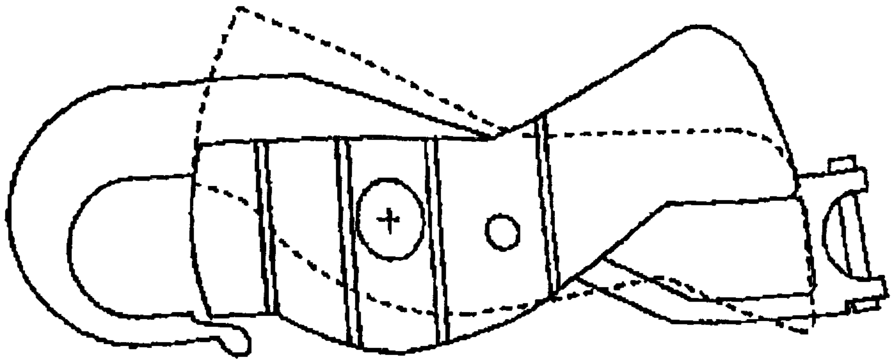


Figure 25. EVA tether tool.

Figure 26. EVA needle-nose pliers.

Comfort testing was provided by use of questionnaires at the end of the dexterity and fatigue tests. The subjects were asked to note, on a picture of a hand, any areas of contact between the glove and their hand. They were also asked to identify the type of contact and the level of discomfort caused by the contact. This questionnaire is included in appendix B.

For gloves further along in the design process, evaluation would include wrist capabilities. The wrist would be tested in the areas of strength, ROM, and dexterity (through the orthogonally placed bolt-hole surfaces). The integrated task test could potentially include wrist actions which would affect the overall results. In this test series, all wrist-specific tests listed above were not performed, however the integrated task test was performed. The pliers tool and tether tasks were chosen as these were the tests most likely to provide meaningful information on finger joint capabilities. Wrist related influences were minimized through placement of the test article.

B. Analysis

Data from tests were statistically analyzed using analysis of variance. Analysis of variance was chosen as it allows evaluation of both the main effects due to pressure glove use, and interaction effects among the independent variables.[61] The test design was within-subject for GS condition with subject strength used as a blocking variable. Therefore, every subject tested in every GS condition. The null hypothesis was that the GS condition had no effect on performance. The significance-level (α) was set at 0.05, meaning that the occurrence of an effect of that magnitude or larger could be expected to randomly occur 5 times in 100. Effects beyond that (P-value $< \alpha$) are referred to as statistically significant, that is, the null hypothesis is rejected. When a significant effect was shown, a post hoc analysis was run to determine which of the GS conditions were significantly different. The Student-Newman-Keuls (SNK) posthoc test was chosen as it makes all pairwise comparisons, and, if in error, it is more likely to determine there is no effect due to GS condition when one exists than to erroneously state an effect due to GS condition where none exists.[63] This helps protect against unfounded claims of potential glove impacts on performance, which could lead to unwarranted design modifications. The software package used for this analysis was Abacus Concepts, Super ANOVA™.

The ROM, grip strength, pinch strength, dexterity, and integrated task tests all showed significant interactions with glove use and/or subject strength. The tactile test showed significant variation due to the size of the gap between the two surfaces. Analyses of all of the tests are discussed in more detail.

In the following discussion, as in the paper throughout, definition of terms is as follows. GS refers to the state of the glove; there were four GS conditions, NG, unpressurized glove (0PSI or Lo), glove pressurized to 4.3 psid (4.3PSI or Mid), and glove pressurized to 8 psid (8PSI or Hi). Run, or run number, refers to a test session in a given GS condition. Each subject performed four runs; each run was performed in one of the four randomly assigned GS conditions. Subject hand strength was classified as high (Hi) or low (Lo).

ROM testing showed a definite interaction with glove. Wearing the glove, in any GS condition, caused significant reduction in MCP ROM. At the highest pressure a significant difference between that GS condition and wearing the glove at 0 psi could be seen. It appears that the glove itself has a major effect on MCP ROM, however at higher operating pressures, further ROM reduction can be found as shown in figure 27. With the glove on, it seems that PIP ROM was improved over the bare hand condition. It is likely that when using the bare hand, subjects tried to keep the rest of their hand flat, yet in the glove, subjects allowed the entire hand to make a gripping motion. A hand positioner may help in this measurement. Figure 28 shows PIP ROM.

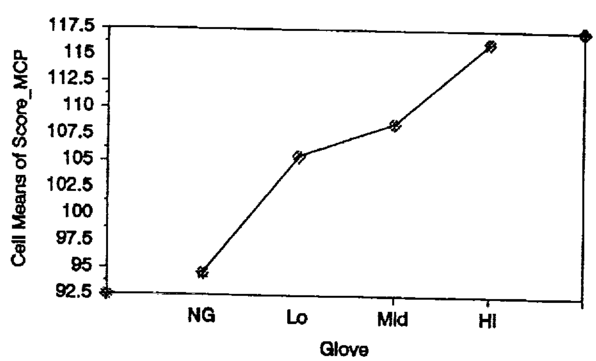


Figure 27. Finger MCP ROM versus GS condition.

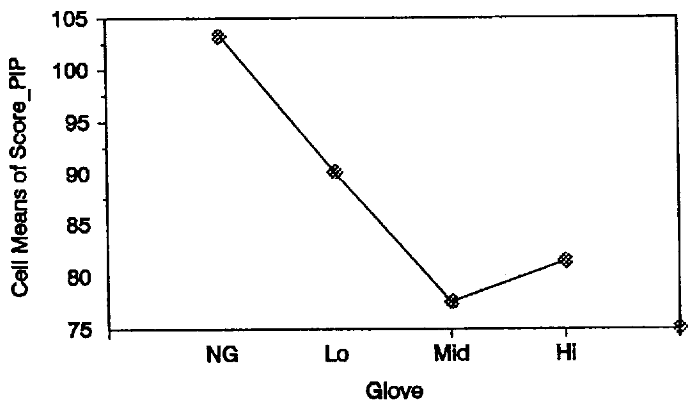


Figure 28. PIP ROM versus GS condition.

ROM of the CMC joint of the thumb is affected by both the glove and pressure. In motions perpendicular to the palm, bare-handed ROM exceeded ROM in any pressurized GS condition, as shown in figure 29. No significant difference was found between bare hand and 0 psi, or between 0 psi and the pressurized conditions.

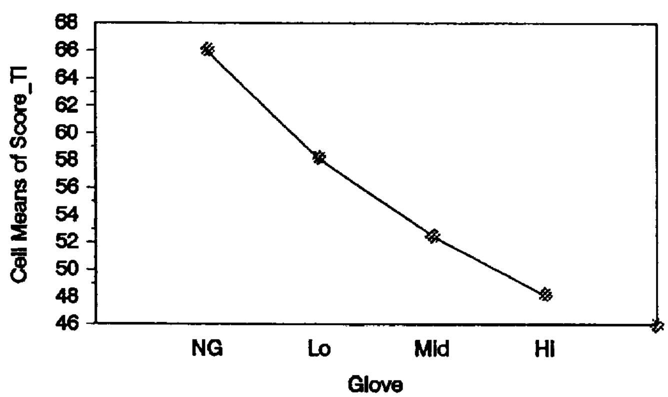


Figure 29. Thumb opposition ROM versus GS condition.

In thumb CMC motion in the plane of the palm, wearing the glove caused a significant reduction in ROM, indicating a need for construction of a glove thumb joint which allows more freedom for the thumb. Addition of pressure also caused some loss of ROM, although this was only significant between the 0PSI and 4.3PSI GS conditions. Figure 30 shows a graph of thumb planar ROM versus GS condition. No significant effects were found in ROM of the index or middle fingers. Although there appears to be a slight increase in ROM at 8 psi, the increase is not significantly different from the 4.3 psi ROM value.

Glove and strength interaction analysis indicates that pressure effects may have affected subjects in the Hi strength category more quickly than Lo strength subjects, however, values for each became similar as pressure was increased.

Wearing the unpressurized glove degraded grip strength from the bare-handed values. Differences between grip strength with the unpressurized glove and 4.3 psid were not significant; however, grip strength was significantly reduced at 8 psid. This is shown in figure 31. High strength subjects showed greater degradation over runs, although subjects in the Hi category produced greater grip force than Lo strength category subjects in all GS conditions.

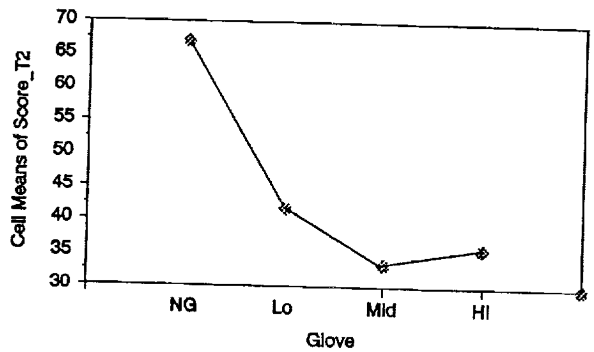


Figure 30. Thumb planar ROM versus GS condition.

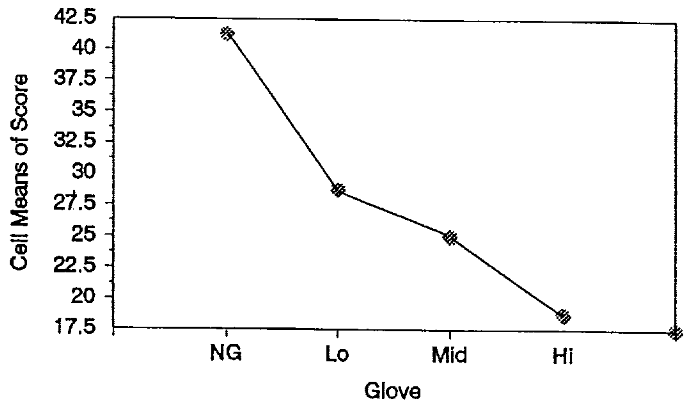


Figure 31. Grip performance versus GS condition.

The plot in figure 32 shows the interaction between attempt and the grip force exerted by the subject. Differences between attempts 5 and 4, 4 and 3, and 3 and 2 are not significantly different as shown by the SNK posthoc analysis. However, a general degradation of grip performance as more attempts were tried is shown. This may be due to subjects getting fatigued as they did more trials. Since there were only five trials, this trend may also reflect greater effort in earlier trials.

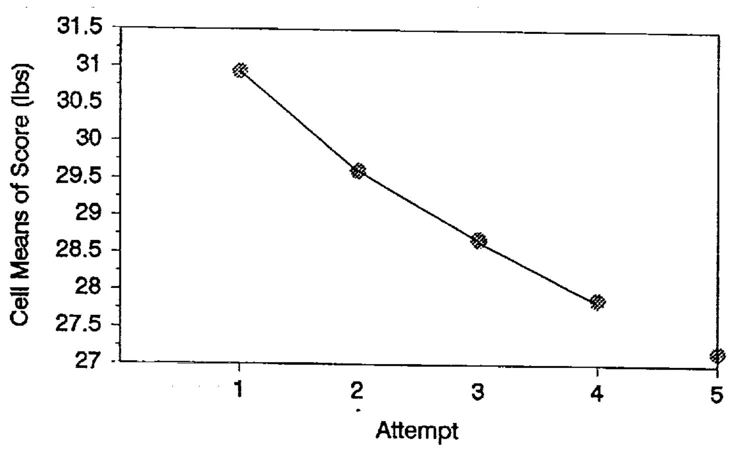


Figure 32. Grip performance versus attempt.

Not surprisingly, in the pinch tests, subjects classified as strong by grip strength also showed greater pinch strength. A significant loss of pinch strength was evidenced between the glove at 8 psid and any other GS condition. No other pairwise comparisons between GS conditions were significant. This indicates that higher pressure was the driving force in pinch performance degradation with this glove design. Tasks requiring key-pinch strength could be affected, especially at higher glove operating pressures. Interaction of pinch strength with GS condition is shown in figure 33.

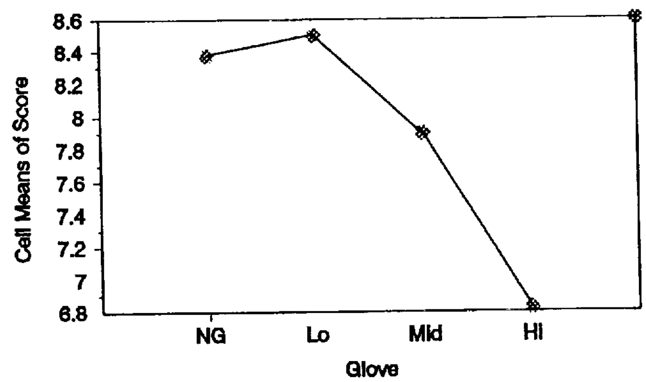


Figure 33. Pinch strength versus GS.

In looking at the results of the digit extension task, it appeared that some interaction due to glove may have occurred. When the SNK posthoc test was performed, however, no pairwise interactions were noted as significant. A less conservative posthoc test, the Fisher's protected least significant difference (LSD),[57 62] was run to see what effects may be significant. Trends seem to indicate that subjects were able to exert more upward force with the glove pressurized. This may be in part due to the expansion of the pressurized glove causing more force to be exerted on the gauge even before digit extension. Results from both the SNK and the LSD tests are in appendix D. It is unlikely that extending a finger from the glove's neutral position against pressure would be easier than doing so with the bare hand or unpressurized glove. Improvements to this test are suggested. A more sensitive gauge, since forces exerted by finger extension are so much smaller than pinch grip forces, would be helpful. Additionally, a more accurate measure might be made by starting the test from the glove's neutral position rather than having the hand flat under the gauge. Accurately measuring a normal force from the neutral position could be difficult, however. Future testing could help clarify the results from this test.

The diverging surfaces test indicated that while subjects took a longer distance to identify divergence with the gap set at 0.5 cm than at the other settings, gap settings of 1.0 cm and 1.5 cm did not produce significantly different results. No interaction between hand strength or GS condition and tactile sensing could be determined. This may be due to the fact that this glove only consisted of two layers, and did not have a TMG covering during tests. Tests with a TMG covering would be advisable before drawing conclusions on the tactile sensing possible with this glove.

Although this test did not provide particularly strong information in this test series, it is still recommended as a part of this protocol as it has worked well in other test series in which it has been applied. Also, with the variation in potential glove designs, from the current shuttle gloves to the MIT "skinsuit" glove, coupled with the fact that tactile feel influences applied grip force, and therefore fatigue,[7 25 28] this sort of test is useful.

Strength had some effect on performance in the peg-bolt test at the 30- and 60- s time intervals. It is likely that stronger hands were better able to overcome glove effects when manipulating the bolts. No significant difference in the number of errors, or drops, was found between subjects in the two hand strength categories.

At 15 s, performance was affected by wearing the glove; differences between the bare-hand and gloved-hand results, whether the glove was pressurized or not, could be seen. Pressure effects became apparent at 30 and 60 s. In fact, subjects were unable to insert any of the bolts when the glove was pressurized, but subjects performed better with the unpressurized glove. The results for 15 and 60 seconds are plotted in figures 34 and 35. No correlation was found between GS and errors.

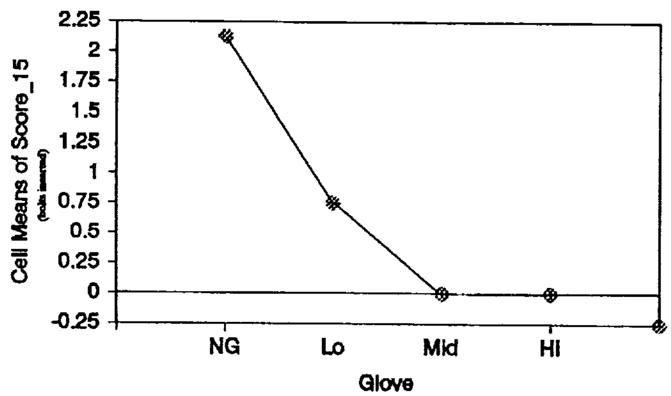


Figure 34. Bolts inserted (mean) versus GS at 15 s.

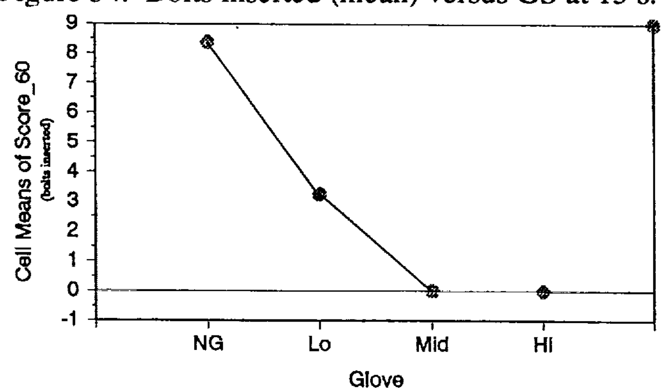


Figure 35. Bolts inserted (mean) versus GS at 60 s.

The integrated task test involved operating two tools, an EVA tether hook and a needle nose pliers, in timed tests. Subjects with stronger hands performed better on the EVA tether part of the integrated test. This may be, in part, due to having to press the two release buttons, on either side of the hook. Most subjects used the thumb and index finger to press the release button requiring some thumb and finger work against the glove effects. However, at 4.3 and 8.0 psi, performance differences between subjects in the two strength categories became no longer statistically significant. A main effect due to glove was apparent.

Bare-handed performance was significantly better than any gloved-hand performance at all time periods. Performance with the unpressurized glove was better than either of the pressurized GS conditions. No significant difference was shown in performance between either of the two pressurized GS conditions. Drops only occurred in the pressurized conditions; the ability to recover the tool was affected by pressure. Figure 36 plots the means of scores at 60 s. The value at GS of Hi is 0.25, and only appears to be zero due to scaling of the plot.

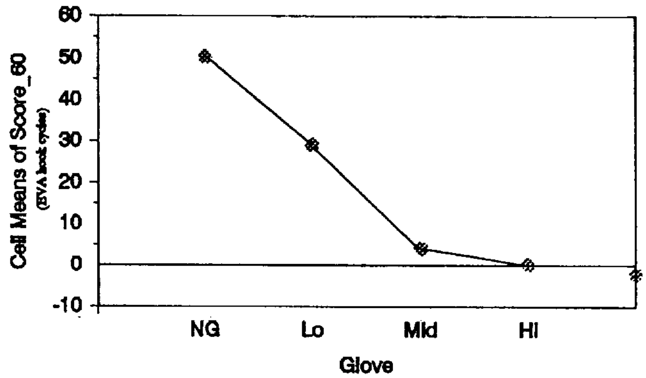


Figure 36. Interaction of GS with EVA tether manipulation.

Unlike the EVA tether test, when operating the pliers, no significant effects due to strength were found. Glove and strength interactions indicate that at the pressurized GS conditions, there is little difference in performance between subjects due to strength. As expected, best performance was achieved with the bare hand. At 30 and 60 s, the difference in performance between wearing the glove at 0 and 4.3 psid is not significant, although it started out to be at 15 s. No significant difference in 4.3 and 8 psid is seen. It appears that wearing the glove reduces performance, and a pressure effect also occurs between wearing the glove (0 psid) and using it at higher pressures.

The fatigue test did not show any significant interactions. Most likely, either a longer duration test, or EMG measurements, would be a better indicator of fatigue induced by EVA glove use.

To see if there were any learning or fatigue effects between runs, performance and run interactions were looked at. In the dexterity and integrated task tests, no interaction between run number and performance was found; that is, subjects were not getting better at performing the task due to practice over runs, nor were they getting fatigued due to runs being performed too close together. These results also indicate that the answers given on the hand comfort questionnaire were accurate; that is, subjects were not experiencing enough glove-induced discomfort to cause difficulties in performing the next test series.

Glove Fit Questionnaires were filled out by subjects after the dexterity and fatigue sections of the test session. These places in the session were chosen since the hand had, in each case, just been through fairly demanding motions more likely to induce glove related discomfort. All subjects indicated contact between their hand and the restraint bar that ran across the palm and back side of the hand. This contact ranged from light and no discomfort, to heavy contact and major discomfort.

An attempt has been made to quantify the comfort data obtained from subject responses to the Glove Fit Questionnaires. As mentioned earlier, sliding scales were used to assess the level of contact and discomfort induced by that contact. To analyze the responses, the hand has been divided into seven regions as shown in figure 37. These regions are the five digits, the palm, and the back of the hand. An overall hand discomfort value was produced by averaging the values in each of the regions. In each region, the worst reported discomfort was used as the value for that region. The results presented here are based on the worst case of the responses given after the dexterity and fatigue tests.

Region	Number
Thumb	1
Index Finger	2
Middle Finger	3
Ring Finger	4
Little Finger	5
Palm	6
Back of Hand	7

Figure 37. Seven regions of the hand used for comfort analysis.

Two analyses were run. One compared all four GS conditions for each of the seven regions and the overall rating. The bare hand condition was taken as the norm, that is, valued at no glove-induced discomfort. Glove-induced discomfort in region 7 was significantly degraded from the NG to any gloved GS conditions. This is shown in figure 38. The overall versus discomfort rating showed the NG condition significantly different than either the Lo or Hi GS conditions.

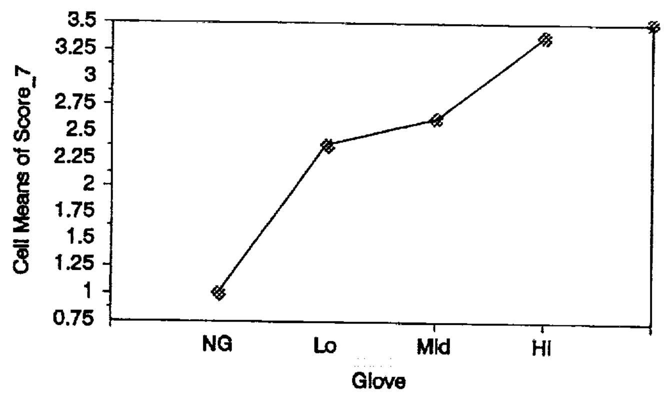


Figure 38. Comfort rating versus GS condition in region 7.

The second analysis compared only the three gloved hand GS conditions. No significant difference in glove-induced discomfort was noted between these three GS conditions in each of the regions. However, for the thumb and digits three and four, differences in noted discomfort were found between subject strength categories. Subjects in the Hi strength category noted more discomfort in digits three and four. Subjects in the Lo strength category noted greater discomfort in the thumb.

In comparing only the three gloved hand GS conditions, overall hand discomfort was not significantly different between them. Comparison of the postdexterity and postfatigue responses was not done, since there was so little difference between the GS conditions.

No interaction between comfort responses and run was found. This indicates that subjects were not experiencing greater discomfort as the test series progressed, and that their responses on the presession hand comfort questionnaires were accurate (no subjects noted that they were experiencing any discomfort which would affect their performance on the current test).

VII. DISCUSSION AND FURTHER RESEARCH

A. Discussion

The protocol described in this paper has shown the ability to drive out differences in glove performance between a gloved hand and the bare hand, and between glove operating pressures. Mature glove designs may also be compared against each other, or a single glove design may be tested to indicate areas for modification. Comparative-performance information is found for six hand performance categories, namely strength, dexterity, ROM, tactile sensing, fatigue and comfort, allowing specific areas for glove improvement to be shown. The integrated task section of the protocol gives the glove or mission designer the option of testing glove performance for a specific mission regime (planetary, orbital assembly) or mission task. Areas for future refinement of this protocol have also been shown by the test. These are discussed in the following section on further research.

If the steps outlined in sections IV and V of this paper are followed, evaluation of a pressure glove with respect to performance may be accomplished. This may be done at either the completion of a glove design, or during the design process, as was done in the tests described in section VI, to assess the glove design's ability to meet its objectives. Classification of the subject population with respect to hand strength and size (when applicable) provides a range of cells over which performance can be assessed. This enables the test results to be applicable for a greater variety of hands. Posthoc tests of effects of potential significance are recommended to determine specific interactions between glove operating states. The flexibility of the protocol makes it applicable to NASA and other users of pressurized gloves, glove designers, and even robotics developers.

In developing the protocol described in this paper, recommendations from previous efforts were incorporated where possible. The glovebox used parallel flat surfaces for videotaping hand motions. The within-subject design helped even out variations in subject perceptions by, in a sense, allowing each subject to act as his or her own control. This is especially useful in evaluating glove performance in areas such as comfort. The protocol was designed to be flexible enough to meet the needs of different users. Glove designers can use the tests to evaluate a design's progress without having to fully design a set of gloves. All tasks could be done one-handed, which is useful if only one glove is available for testing. Gloves can be compared by task or capability if only a few features are to be tested. Additionally, the integrated tasks may be incorporated to allow testing specific to a particular EVA mission need. An attempt has been made to quantify glove-induced discomfort to various regions of the hand. Other divisions of hand regions may be useful for this type of evaluation, as well. Along with single glove design evaluations, glove comparisons may be performed between different glove designs. Again, this comparison may be of the gloves overall as they pertain to a mission, or to just a few of the gloves' features.

If the operating parameters and potential mission needs are known, evaluation of mechanical end effectors may be performed using aspects of this protocol with only minor changes to the test articles. ROM, grip, and extension strength may impact certain missions. Since in cases where a robot would be used the mission tasks would be approximated in advance, the integrated task tests are especially applicable for manipulator testing. Varying the pressure (GS condition), would not be necessary, nor would fatigue testing.

In any glove box testing, there are limitations as to what motions and strengths can be ascribed solely to the actions of the hand. Finger strength is dependent on muscles in the arm; wrist ROM may be dependent on positioning of the whole forearm. However, in comparing the effects of any *glove design* on these variables, a glove box is effective in that the restrictions of the glovebox environment are placed on every glove tested.

The prototype glove as tested did not have the bladder or spring dorsal assemblies. The fabric assembly was used to set the glove's neutral position. The glove design did not attempt to address thumb abilities, so although subjects reported some difficulty with thumb mobility, these concerns were beyond the scope of these tests. Additionally, the glove was not designed to be used at 8 psi, so although tests were run at that pressure, difficulties encountered with the glove's performance at the higher pressure were also beyond the scope of capabilities addressed in the current design. These higher pressure tests did, however, point out some areas where pressure effects were prominent in reducing performance with respect to the bare hand.

Increased pressure did reduce grip strength, indicating one potential area for improvement. This concern is likely to be addressed by the addition of the dorsal bladder or spring assembly. Wearing the glove reduced MCP ROM to 88 percent of bare-handed ROM; MCP ROM was further reduced to 85 percent at 4.3 psi. If individual finger mobility is enhanced by use of the bladder system, this concern may be overcome with further development of the prototype. Dexterity was impaired when using the glove; at 0 psi, subjects still experienced difficulty in manipulating the bolts. During discussions after the tests, several subjects commented that the excess material along the seams of the fingers added to their difficulty in manipulating objects. When pressure was added, further reductions in dexterity performance occurred. This indicates a need for improving individual finger mobility and overall hand dexterity in future versions of the glove. Addition of an overlayer (TMG) is likely to affect dexterity. Performance degradation by GS condition is tabulated in appendix D.

When filling out the Comfort Questionnaire, trends indicated discomfort along the back of the hand. This was the case for any gloved hand GS condition with respect to the ungloved hand. As this is the intended region for addition of the bladder or spring assemblies, care should be taken to avoid inducing further discomfort through the addition of these assemblies. Response to the Comfort Questionnaire indicated a need to redesign the palm restraint system. Most subjects encountered discomfort due to the palm restraint bar. Questionnaire responses also noted an interaction between subject strength and thumb discomfort, with Lo strength subjects having more discomfort in the thumb region. This may be overcome once the thumb region is developed, however, test results indicate that the user's strength may affect their response to any thumb region design. Therefore, some allowance for customization of the thumb region for the individual user might be beneficial. Hi strength subjects noted more discomfort in the middle and ring fingers due to using the glove at pressure than Lo strength subjects. Again, user strength affects reaction to the glove finger design, indicating a potential benefit to designing in the ability for the user to modify fit of the glove fingers.

B. Further Research

Several areas of the protocol might be improved by future developers. Further refinements are needed in the digit extension test and the fatigue test. A more sensitive gauge in the range of 1 to 4 lb or so would be useful for the digit extension measurements. Performing measurements from the glove's neutral position, and the bare hand's neutral position for the NG condition, would provide a more meaningful measure. Using a combination of EMG measurements and a longer duration fatigue test would be useful in determining fatigue induced by glove use.

The Glove Fit Questionnaire provides a good way for subjects to identify the location of discomfort, and the scaled responses help in driving out levels of discomfort. In future testing, it may be helpful to ask subjects to give a rating to each of the selected regions rather than just identifying discomfort on a picture of the hand. The contact scale responses were not evaluated.

To quantify comfort, the hand was divided into seven regions. While these regions can be easily identified, other divisions may also be useful. The palm and back of hand areas cover several dynamic ranges of the hand, including CMC and even one "edge" of MCP bending. The hand was not divided into more regions in order to reduce the possibility of assigning undue significance to reported discomfort. However, using other divisions, such as the "ulnar" and "radial" regions of the hand rather than the front and back, might be useful.

One other way to compare GS conditions, or different gloves, may be to apply the paired comparison method used in a study to evaluate crew restraint devices.[63] In this method, subjects were asked to compare different devices against each other with respect to a set criteria. This method appears to be most useful when subjects have had time to become familiar with one or more gloves, and tests are not scheduled too far apart, so subjects can provide a meaningful comparison between the glove at different pressures, or between different gloves.

In testing this glove, the fit was fairly tight for the subjects selected. There was no room for inserting sensors inside the glove, or the wearing of a sensored glove. However, for other gloves, determining the position of the hand inside the glove could be done through the use of a sensored glove or similar device, or by using force sensors on the inside of the glove to determining points of contact between the hand and glove. This would also be useful in determining which part of the hand was exerting force against the glove to perform a specific task. The technology represented by the VPL DataGlove is becoming mature enough to use in ROM testing of normal subjects,[64] and eventually in rehabilitation.[65] Pressure forces between the fingers and glove surfaces might be measured by thin-film pressure sensitive sheets,[66] or possibly piezoelectric sensors.

Overall fatigue will be the result of many coupled effects between glove design, suit design, and task design. Less strength in the hand may be compensated for by body positioning or arm strength. An individual's lack of dexterity may impede progress in one part of a task, while that person's strength may aid in another task section. A particular glove design may not always be the determining factor in these instances.

It is useful to measure static work (force * duration) in EVA tasks since hands provide stabilization during task performance. Most EVA tasks are defined as one-handed tasks to allow the other hand, along with the feet, to act as a stabilizer. These two attach points between the astronaut and the task provide a means of controlling the body's position with respect to the task article in all degrees of freedom except yaw along the axis defined by the attach points. The hand performing the task, and muscle exertion by the astronaut, control this rotation and fine positioning of the body relative to the task.

Most glovebox tasks only can measure dynamic work and the attendant fatigue and discomfort caused by attempting dexterous (fine motor) tasks. Dive testing while putting sensors on the suited diver can allow concurrent measurements of dynamic and static work effects. It may be possible to subtract out the dynamic (glove box) fatigue effects from the overall measured dive test results through careful test design and measurements. One project at Marshall Space Flight Center's Neutral Buoyancy Simulator facility involves adding the capability to gather a suited dive subject's heart rate, and temperature during a dive.[67] In astronaut training at NASA JSC, WETF training has been found to be a good analog for actual space operations.[68] Underwater testing of a glove design in conjunction with the EMU suit may provide some insight into some of these coupled effects. While it is not possible to undertake testing of enough people to provide a statistical basis for analysis during this project, this could be done at a later time by NASA or other interested researchers.

At this time, only the restraint layer with fabric assembly of the Vanderbilt University prototype glove has been tested. Once the control system is added, the glove can be retested, and results for the spring and bladder assemblies compared with results from this test. This would allow an evaluation of performance of the glove control system with respect to the fabric joints and restraint layer; in effect, a comparison of the impact of the force-assistance and the restraint layer design on the glove's overall performance. Evaluation of the bladder system versus the spring system in improving performance would point out areas of improvement for each and might indicate a preferred design. Doing sequential tests such as these is an example of mid-design evaluation of specific glove features, and is a way to evaluate the effectiveness of a particular design course.

APPENDIX A

GENERIC EVA ACTIVITIES

Generic EVA Activities

The "The Human Role In Space" (THURIS) study produced 37 generic space activities, 13 of which potentially involve EVA gloved-hand motions. These 13 are numbers 2, 9, 10, 15, 18, 25, 29, 30, 31, 32, 33, 36, and 37 in the following tables. Figures 39 and 40 were taken from the THURIS report.[4] These tasks may involve tool use, or be designed for use of the gloved-hand alone. Tasks such as those described in item number 26 would be very difficult to accomplish with the gloved-hand. Designing tasks and equipment for EVA operations would alleviate some of these problems. However, in the case of an emergency such as an unscheduled depressurization of one of the Space Station *Freedom* (S.S. *Freedom*) modules, crewmembers could find themselves being required to perform precision tasks.

Generic Space Activities	Source					
	AXAF	(1) Skylab	(2) Space Platform	Space Station	(3) ARAMIS Study (MIT)	Life Sciences Laboratory
1. Activate/Initiate System Operation	•	•	•	•	•	•
2. Adjust/Align Elements		•		•	•	•
3. Allocate/Assign/Distribute		•	•	•	•	•
4. Apply/Remove Biomedical Sensor		•		•	•	•
5. Communicate Information	•	•	•	•	•	•
6. Compensatory Tracking				•	•	
7. Compute Data	•	•	•	•	•	•
8. Confirm/Verify Procedures/Schedules/Operations		•	•	•	•	•
9. Connect/Disconnect Electrical Interface		•	•	•	•	•
10. Connect/Disconnect Fluid Interface		•	•	•	•	
11. Correlate Data		•	•	•	•	•
12. Deactivate/Terminate System Operation	•	•	•	•	•	•
13. Decode/Encode Data			•	•	•	
14. Define Procedures/Schedules/Operations		•	•	•	•	•
15. Deploy/Retract Appendages	•	•	•	•	•	
16. Detect Change in State or Condition		•		•	•	•
17. Display Data		•	•	•	•	•
18. Gather/Replace Tools/Equipment	•	•	•	•	•	•
19. Handle/Inspect/Examine Living Organisms						•
20. Implement Procedures/Schedules		•	•	•	•	•
21. Information Processing		•		•	•	•
22. Inspect/Observe		•	•	•	•	•
23. Measure (Scale) Physical Dimensions		•			•	
24. Plot Data		•	•	•		•
25. Position Module	•	•	•	•	•	•
26. Precision Manipulation of Objects		•		•		
27. Problem Solving/Decision Making/Data Analysis		•	•	•	•	•
28. Pursuit Tracking		•	•	•	•	
29. Release/Secure Mechanical Interface	•	•	•	•	•	•
30. Remove Module	•	•	•	•	•	•
31. Remove/Replace Covering		•	•		•	•
32. Replace/Clean Surface Coatings	•		•			•
33. Replenish Materials	•	•		•	•	•
34. Store/Record Elements		•	•	•	•	•
35. Surgical Manipulations						•
36. Transport Loaded	•	•	•	•	•	•
37. Transport Unloaded	•	•	•	•	•	

(1) Includes EREP and ATM Activities
(2) Includes Activities Derived from the Analysis of Space Platform Ground System Data Management Study
(3) Includes 330 Generic Functional Elements Derived from the Geosynchronous Platform, Advanced X-Ray, Astrophysics Facility, Teleoperator Maneuvering System and Space Platform

Figure 39. Sources of generic activities.

1. Activate/Initiate System Operation: Those events and/or sequences involved in the activation or initialization of a space-based system or subsystem.
2. Adjust/Align Elements: Those adjustment activities involved in such operations as alignment of critical elements, fine tuning of precision electronic equipment, antenna pointing, and remote camera focusing operations.
3. Allocate/Assign/Distribute: Those activities involving the reallocation or redistribution of resources: e.g., the redistribution of power, coolant flow, etc., to sensitive subsystem equipment to reflect operational needs or contingency operations.
4. Apply/Remove Biomedical Sensor: Those unique activities associated with the installation/removal and cleaning of sensors used to obtain biomedical data from a test source.
5. Communicate Information: Those activities involving the establishment of the communications link and the transmission of information from one source to another. It includes the verbal or visual interchange between two crewmen as well as the electronic transference of scientific information from a space probe to a terrestrial-based user.
6. Compensatory Tracking: Those activities involving continuous control adjustments to null an error signal against a fixed reference.
7. Compute Data: Those activities requiring a mechanized form of data processing, such as in structural analyses, computation of positions of celestial bodies, or other forms of numerical computations.
8. Confirm/Verify Procedures/Schedules/Operations: Those activities involving the assessment of whether or not a previous event has in fact been accomplished (such as a system verification or checkout), or a procedure satisfied, or a schedule met.
9. Connect/Disconnect Electrical Interface: Those activities requiring the completion or termination of an electrical interface. They may involve use of blind-mated/self-aligning connectors, multiturn screw-drive interface plates, or similar devices.
10. Connect/Disconnect Fluid Interface: Those activities requiring the completion or termination of a fluid interface. They may involve use of a simple plug-in, sleeve-ocx connection, multiturn screw-drive interface plates, or similar device.
11. Correlate Data Those activities involving the identification of positive or negative relationships or commonalities among data sets, such as organizational structures, characteristics, or processes.
12. Deactivate/Terminate System Operation: Those events and/or command sequences involved in the termination or deactivation of a space-based system or subsystem.
13. Decode/Encode Data: Those activities involving the conversion of data into either its original form or into a form compatible for transmission: e.g., converting transmitted digitized data into its original analog form or digitizing analog data for transmission to the ground station.
14. Define Procedures/Schedules/Operations: Those activities involving logical deductions or convergent production leading to development of procedures, schedules, or operations with predictable outcomes.
15. Deploy/Retract Appendages: Those activities associated with the extension of a hardware element to a position where its assigned function can be realized, or conversely, the stowing of that hardware element based on task completion or safety considerations.
16. Detect Change in State or Condition: Those activities wherein the departure of a parameter from its original or reference state or condition is required to be sensed or observed.
17. Display Data: Those activities involving the presentation of information/data by visual, auditory, or tactual means.
18. Gather/Replace Tools/Equipment: Those activities involved in the obtaining or returning of tools or equipment used to perform a specific task, such as collecting or replacing maintenance tools or donning/doffing the Manned Maneuvering Unit.
19. Handle/Inspect/Examine Living Organisms: Those activities involving the unique operations associated with working with living organisms. These activities involve the manipulation and general handling of animals, ranging from stroking to inspecting or examining anatomical characteristics.
20. Implement Procedures/Schedules: Those activities involving the instituting and carrying out of procedures or schedules (such as updating a mission model/schedule) as distinguished from activating or initiating system operations.
21. Information Processing: Those activities involving the categorizing, extracting, interpolating, itemizing, tabulating, or translating of information.
22. Inspect/Observe: Those activities involving the critical appraisal of events or objects. They may include the verification or identification of a particular elements, such as damage inspection of a returning critical test vehicle, observation and identification of a celestial object, or behavior of a living organism.
23. Measure (Scale) Physical Dimensions: Those activities involving the estimation or appraisal of a dimension against a graduated standard or criterion.
24. Plot Data: Those activities involving the mapping, displaying, or locating of data by means of a specified coordinate system.
25. Position Module: Those activities involving the positioning of a component into a desire orientation: e.g., installing a new component, or tilting a payload into its launch orientation.
26. Precision Manipulation of Objects: Those activities involving tasks that require a high degree of manual dexterity, such as the assembly/disassembly of small intricate mechanisms, or the installation of measurement sensors, i.e. strain gages, thermocouples, etc.
27. Problem Solving/Decision Making/Data Analysis: Those judgmental and sometimes creative activities involving the drawing of inferences or conclusions through the use of cognition, convergent or divergent production, memory, and comparative evaluation. functions to be performed may include analyzing, calculating, choosing, comparing, estimating, or planning.
28. Pursuit Tracking: Those activities involving continuous control adjustment to match actual and desired signals when the desired or reference signal is continually changing.
29. Release/Secure Mechanical Interface: Those activities involving the manipulation of a mechanical interface ranging from a simple one-handed, over-center latch application to a high-torque, multiturn threaded fastener. May involve manipulation of multiple fasteners arranged in various patterns or configurations.
30. Remove Module: Those activities involving the physical extraction or removal of a component after the mechanical, electrical, or thermal interfaces have been released or disconnected.
31. Remove/Replace Covering: Those activities involving the removal or reinstallation of an access covering or a protective covering as required to gain access to system elements or to cover them up upon completion of the work.
32. Replace/Clean Surface Coatings: Those unique activities involving the restoration of a degraded/contaminated surface coating, such as replacing a radiator's thermal coating or cleaning and optical system's viewing surface.
33. Replenish Materials: Those activities involving the resupplying of consumables, such as refueling a spacecraft, recharging an optics cryo-based cooling system, or providing food supplies to an animal holding facility.
34. Store/Record Elements: Those activities involving the recording or storage of items for both short-term and long-term periods: e.g., recording/storage of experimental data or the temporary storage of a biomedical sample.
35. Surgical Manipulations: Those activities, such as a surgical procedure or a dissection, including tissue sample acquisitions, that require a high degree of skill and knowledge as well as manual dexterity.
36. Transport Loaded: Those activities involving the conveying of a physical object by some transportation device from one location to another: e.g., the transporting of a component via a crewman or a remote manipulator system.
37. Transport Unloaded: Those activities involving the movements of an unloaded individual or device from one location to another: e.g., the movement of a crewman to a worksite without carrying tools or equipment, or the movement of a remote manipulator system with nothing attached.

Figure 40. The 37 generic activities.

EVA Task Modeling

To evaluate a glove's performance, it is necessary to know the conditions under which the glove will be used. Missions requiring EVA can vary from low-Earth orbit (LEO) shuttle cargo bay tasks to Martian surface habitat assembly. Gloves can be optimized for a particular mission set, such as lunar operations. A performance metric, then, needs to evaluate the glove performance relative to the missions the glove is designed for. For example, on gloves designed for lunar operations, how much would the addition of dust shielding features reduce the allowable ROM of the gloved hand? The evaluation of glove performance on mission-specific tasks may also be affected. This can be reflected in the design of an integrated task section of the test protocol.

EVA may be done under various conditions, depending on the nature of the mission. Current tasks would emphasize satellite servicing activities performed in or near the shuttle cargo bay. Space station era tasks may include satellite servicing activities along with construction/assembly and RMS/MSC operation and control.

Lunar and Mars missions could require habitat construction, soil sampling (involving the use of task-specific equipment), rover, and probe operation. This makes it difficult to establish a single set of criteria for all EVA glove design. Changes in suit design, including changes in operating pressures, add to this difficulty.

In 1985, the following requirements for EVA glove performance were stated.[7] In the area of hand motion, typical motions to be allowed by the EVA glove are:

Finger twirling, where the minimum object diameter is 0.5 in

Finger/palm grip and wrist motion using a tool with minimum diameter or 1.0 in.

Two near-term potential mission regimes are discussed below. These regimes—orbital operations, including S.S. *Freedom* and Lunar/Mars—were chosen because they encompass the major program goals of NASA where EVA would be involved.[69 70] Additionally, the European Space Agency and the Commonwealth of Independent States (CIS) have indicated similar plans to operate in Earth orbit, with the CIS considering potential planetary missions in the future.[71 72] Although glove design is an evolutionary process, the mission needs, and the tools developed for the mission, will influence glove design goals.

Orbital Operations

Gloves will need to work with the entire EMU suite. The space shuttle EMU is designed to be used for EVA sorties of up to 7 h maximum: 6 h of which are spent performing useful tasks and 30 min of which are reserved. During the course of a sortie, the average metabolic rate of the crewmember is not to exceed 1,000 Btu/h.[73]

Currently, the shuttle EMU suit operates at 4.3 psid. A minimum pressure of 3.1 psid is required to protect the crewmember from hypoxia. Suits with operating pressures of 8.0 psid are being considered in order to reduce the time needed to prepare for EVA.[74]

The current EVA gloves can be worn for up to 7 h, and allowing grasping of handholds and tools for short periods of time without inducing undue hand fatigue. Figure 41 shows the work volume for the gloved hand.[74]

Several attempts have been made to break down EVA glove activities into action primitives.[7 10 24] This has usually produced a set of common motions of the gloved hand. Integrated task testing has been suggested in evaluating a glove's interaction with tools to be used on a mission or a set of missions.[7 10 74] Shuttle cargo bay activities often require the use of a basic set of EVA tools. A basic tool set is provided for all shuttle missions.[17] A diagram of EVA items flown on every shuttle flight for contingency operations is shown in figure 42.[75] Many EVA tools used on previous shuttle missions are off-the-shelf tools modified to aid grip and add tethering capability.[76] Some potential orbiter EVA tasks, taken from the "Space Transportation System—EVA Descriptions and Design Criteria" document[74] are shown in figure 43.

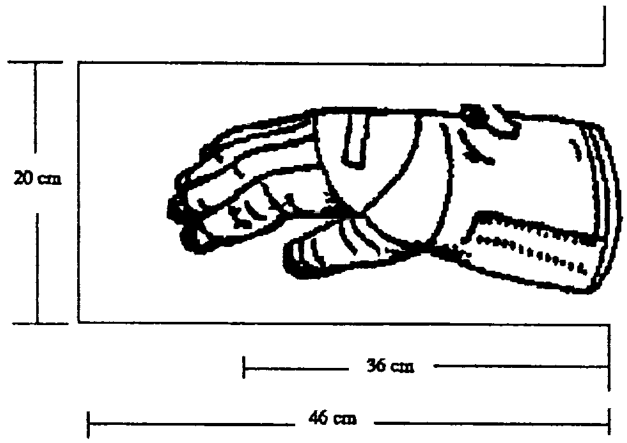


Figure 41. Work envelope for gloved hand.

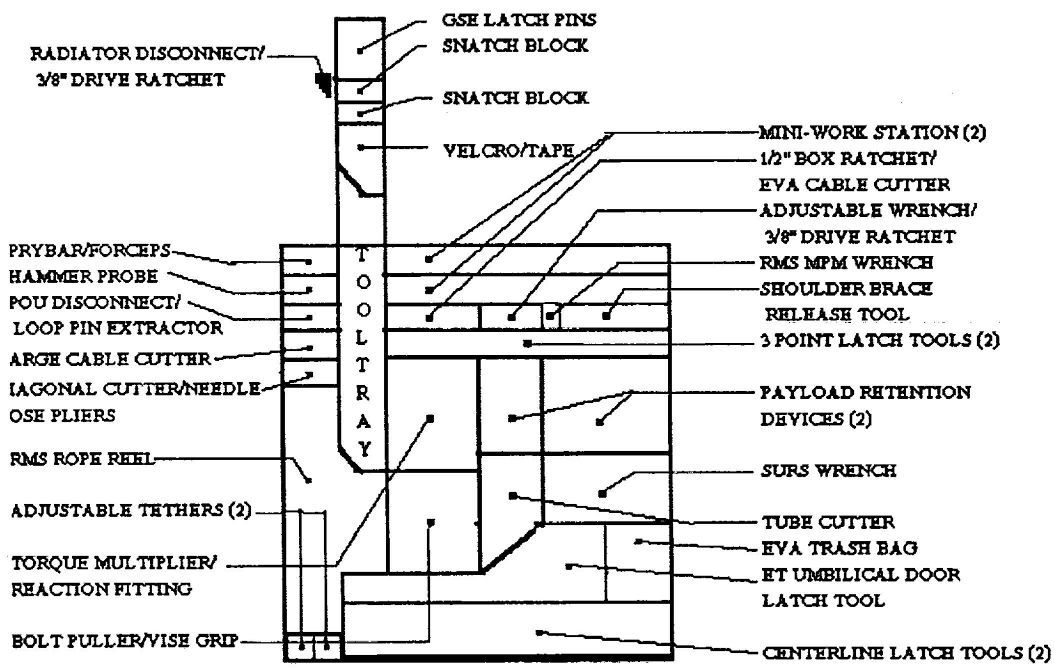


Figure 42. Provisions stowage assembly (PSA)—inboard stowage.

Failure	Procedure	Support provisions
Mechanical jam, all systems	Locate and remove jam	Jam removal tools
Radiator drive failure	Disconnect radiator drive assembly, manually stow	Drive mechanism shear pin 3/8-in. ratchet 3/8-in. extension with 1/4-in. hex head
Payload bay door drive failure	Disconnect power drive unit (PDU) or Cut door drive linkages (6) then Manually close door	PDU disconnect tool Tube cutter Restraint tape EVA winches (2)
Bulkhead latch failure	Install latch bypass tool(s)	Three-point bulkhead latch tools (8) Portable foot restraint with adjustable boom
Centerline latch failure	Install centerline latch bypass tool	Centerline latch bypass tools (4) Portable foot restraint with centerline clamp
Airlock latch failure	Disconnect latch(es) from actuator	3/8-in. ratchet with 7/16-in. socket Adjustable wrench EVA removable bolts (11 per hatch)

Figure 43. Shuttle orbiter EVA tasks.

EVA tasks can vary from the simple to the complex. EVA mission criticality is defined by three levels: mission enhancement, mission-success, and safety critical. Mission enhancement EVA's are those which add greater achievement to a mission; mission-success EVA's are those necessary to achieve mission objectives, for example, the Hubble space telescope repair mission will require EVA; safety critical EVA's are those necessary to assure safe completion of the mission. Safety critical EVA's are often unplanned contingency sorties. Some potential contingency EVA's are described in the above mentioned appendices. EVA complexity is defined as simple (no special tools or restraints required), intermediate (some special tools required, but task is procedurally simple) and complex (task requires significant extension of capabilities, new tools, and/or overcoming significant access or restraint problems).[76]

Space station assembly poses some additional problems. The changes in environment, EVA sortie times, and tool interfaces described here are a few of the differences between S.S. *Freedom* and shuttle operations. Additionally, the life cycles for projected higher pressure S.S. *Freedom* era suits may exceed 20 years, increasing the need for maintainable longer-life glove components.[77]

The colder environment encountered during S.S. *Freedom* assembly could impact the TMG design. This may prompt the use of mission-specific TMG's.[51] In this case, specific integrated task tests may be useful in evaluating the various TMG/glove designs.

EVA airlock egress tasks would include opening equalization valve assemblies, and connection to umbilicals for performance of a final EVA suit check once the crewmember had entered the crewlock. The EVA crewmember may also be required to operate the airlock depressurization assembly before final egress. Suit doffing and the operation of the above-mentioned assemblies would be required upon ingress.[73 78]

Space station assembly may also include the need to cooperate with robots.[1 79] Operating tools designed for use by robots, as well as the ability to operate hand controllers may be required. This task could be considerably eased if tools were designed for robotic and EVA use, and tools necessary for potential robot repair were somewhat standardized with tools needed for space station tasks.

Hand controllers, similar to those to operate the current shuttle remote manipulator system (SRMS), will be operated by an astronaut during EVA.[80] In designing hand controllers, the degree of precision required to produce a desired effect may impact, or be impacted by, glove performance. For one thing, in teleoperation, the ratio of control movement to the indicator or end effector movement becomes important with respect to the amount of time required to perform motions with a given precision.[52 81] Determining this control to movement ratio is a critical step in teleoperator controller design. An operator's ability to produce precision movements may be affected by the gloved hand's tactile sense, or even finger dexterity.

EVA handholds are used on shuttle cargo bay missions. Handholds are also planned as an integral part of the S.S. *Freedom* exterior design. Tethers would be used on all orbital missions such as shuttle cargo bay activities and S.S. *Freedom* assembly.

Lunar/Mars Operations

Some proposed lunar mission scenarios would require in excess of 150 EVA hours in a single mission, contrasted with approximately 160 lunar EVA hours during the entire Apollo program.[82] Increased reliability and maintainability against the extremes of the surface environment will impact the design of EVA suits and gloves. Habitat construction, as well as the conducting of surface science experiments is likely to influence glove design parameters. Lunar/planetary habitat assembly missions will require the use of standard and specialized tools, although possibly over a longer period of time than shuttle missions.[82]

Mars missions have been estimated to be approximately 470 days in duration, with 20 days of that time spend on the Martian surface.[83] Mars missions are likely to have fewer astronauts on a given EVA sortie, however, the sorties will be longer in duration. This, coupled with the longer mission duration, will make in-flight maintainability of all suit components more critical.[84]

Since so much EVA will be required for productive lunar or Mars missions, increasing suit mobility, including glove mobility, will be necessary. One criteria for planetary surface operations, then, is increase gloved-hand ROM over a longer period of time. Developing increased suit and glove mobility is a concern common to space station and planetary mission design.[84]

These are just a few of the concerns brought up by different mission regimes. A glove evaluation protocol needs to respond to the mission requirements, both in evaluation of basic glove characteristics, such as ROM, and in testing "real-world" tasks. During the glove design process, glove features may be tested versus potential mission needs. For example, planetary gloves may need more shielding from the elements, making individual joint dexterity testing more important during the design process.

APPENDIX B

HAND AND GLOVE QUESTIONNAIRES

The Hand Comfort and Glove Fit Questionnaires are shown. These questionnaires use a pictorial representation of the hand and a ranked comfort and/or contact scale for subjects to evaluate hand and glove condition.

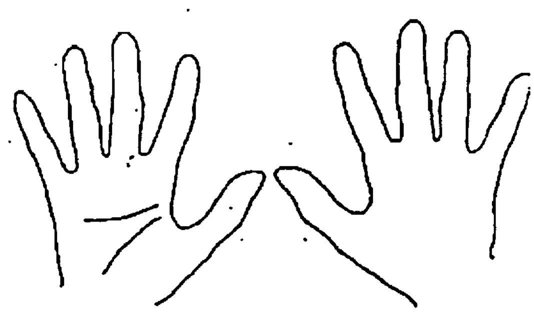
Hand Comfort Questionnaire

Date: ________

Subject: ______________________________
If your hand is experiencing no discomfort check here: ________

On the diagram below, indicate any areas of current discomfort, and indicate type.

Number	Type of Discomfort
1	Blister
2	Hot Spot
3	Bruise
4	Other Soreness (Please Describe)
5	Cramp



If you indicated any discomfort above, how much do you think it will affect your participation in today's test. Will it bother you:

None A Little Some A Lot Too much to do test today (Circle One)

Figure 44. Hand Comfort Questionnaire.

Glove Fit Questionnaire

Subject: ____________________

Date: __________ Test Point: After DEX After FAT

Glove Status (glove on/off or pressure): __________

On the diagram below, indicate all areas of contact between your hand and the glove. Wherever contact is indicated, list type of contact and level of discomfort using letters and numbers from the charts.

CONTACT		DISCOMFORT	
Number	Contact Type	Letter	Discomfort Intensity
1	Light Contact	A	No Discomfort
2	Moderate Contact	B	Mild Discomfort
3	Heavy Contact	C	Uncomfortable
4	Pressure Point	D	Very Uncomfortable
5	Pinching	E	Intolerable
6	Chafing		
7	Other		

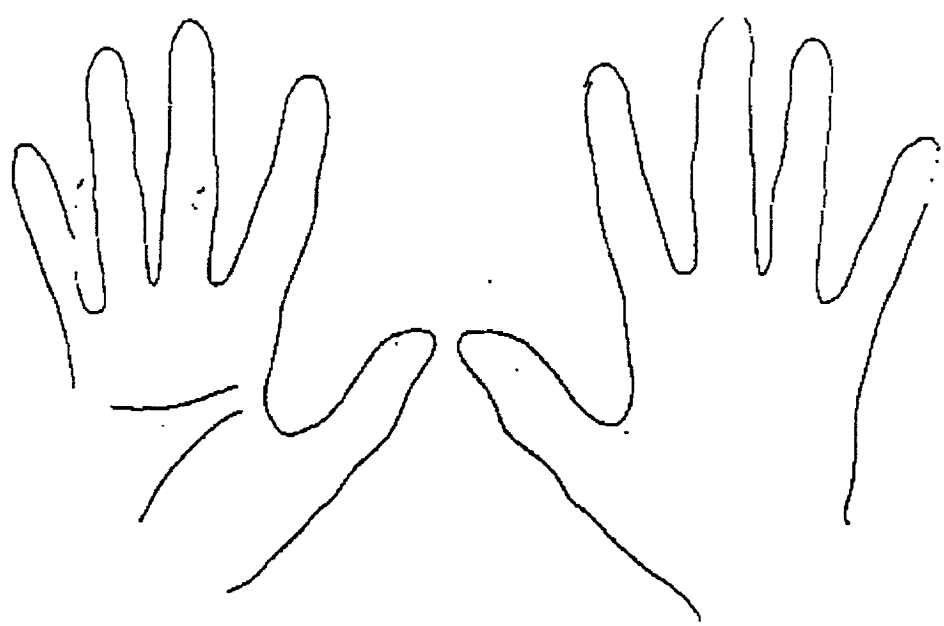


Figure 45. Glove Fit Questionnaire.

APPENDIX C

VIDEO EVALUATION OF RANGE OF MOTION DATA

Video was taken of the hand ROM tests. The hand motion plane and the video plane were kept parallel to avoid incorrect angle readings. Evaluation of this video data was done by capturing screens of the joint at maximum range and taking measurements from the image captured. This was facilitated by use of an image analysis program developed by Richard Norman of the NASA-MSFC aerophysics branch. For these measurements, only the angle measuring capability of the program was used.

The diagram shows how a system for evaluating video data could be set up. This was the system used in evaluating ROM data from this test. The elements of this system are a time base corrector (TBC), a genlock, a VCR, a Commodore Amiga (500 or better) with 1084 monitor, and a second monitor which can accept NTSC in from the VCR. The TBC stabilizes the VCR signal. The genlock mixes the Amiga and VCR/TBC signals and sends them to the second monitor. An image may be captured on screen on the second monitor, and the desired angles measured.

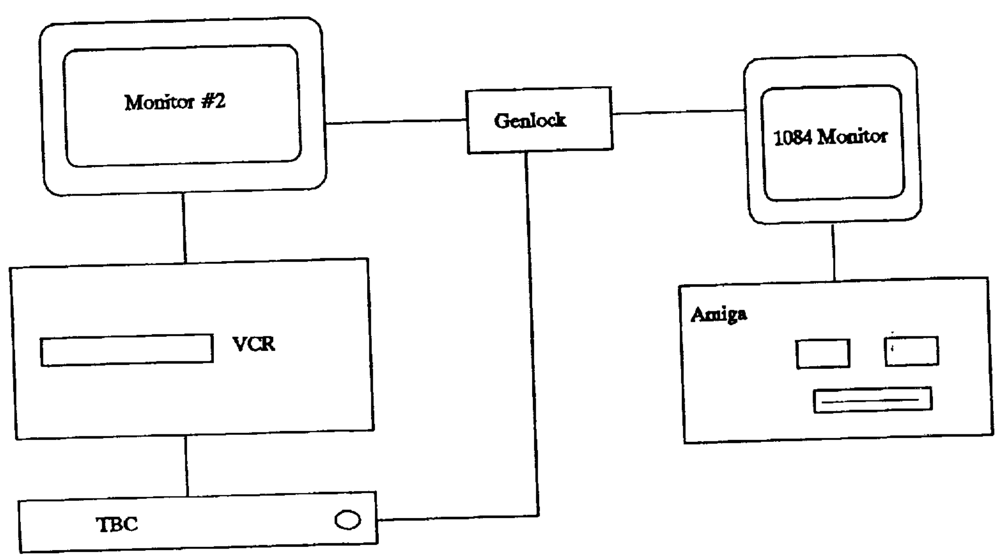


Figure 46. Video image analysis hardware setup.

APPENDIX D

GLOVE TESTING DATA

The eight final subjects are referred to as S1, S5, and so on in the following tables. Runs are labeled R1 through R4; and glove status (GS) condition is referred to as Glove in many of the following figures. Glove categories of NG, Lo, Mid, and Hi refer to no glove, 0 psi, 4.3 psi, and 8 psi, respectively. Subjects S1, S9, S11, and S13 were in the Hi strength category. Subjects S5, S6, S12, and S15 were in the Lo strength category. Data for each of the tests are presented in this appendix.

For each category, the raw data are presented first. These are the data taken as the subject performed the tasks. The next figure in each section is the model of the test data. The calculated P-value is presented here. A P-value of less than 0.05 in any row of the model table indicates a significant interaction between task performance and that effect. For these cases, means tables, and SNK tables are presented in following figures. Graphs of the Means tables are then presented. Finally, in cases where a significant interaction occurs with a crossed effect, for example, Run * Strength, the SNK was calculated with a spreadsheet, and that table is presented in a figure.

For each test, sets of tables for each of the groupings listed above, that is Raw Data, Model, Means tables, SNK, graphs and calculated SNK are presented as one figure. In a few tests, more than one model was run; usually one model was for interactions with Glove (GS) and another for interactions with either Runs a number of Attempts. In these cases, the Model tables are presented as two figures. For range-of-motion (ROM) testing, each measurement is presented separately.

Range of Motion (ROM)

T_1 refers to thumb CMC motion perpendicular to the palm. T_2 refers to thumb CMC motion in the plane of the palm. D_1 refers to index finger extension, and D_2 refers to middle finger extension. ROM test data is shown below. Score refers to Angle in degrees. Smaller angles indicate greater ROM for MCP and PIP measurements. Figure 47 presents ROM data.

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ROM RAW SUBJECT DATA										
	Subject	**Strength**	**Glove**	**Run**	**Score_MCP**	**Score_PIP**	**Score_T1**	**Score_T2**	**Score_D2**	**Score_D3**
▲ **Type:**	Category	Category	Category	Category	Integer	Integer	Integer	Integer	Integer	Integer
▲ **Source:**	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
▲ **Class:**	Nominal	Nominal	Nominal	Nominal	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
▲ **Format:**	*	*	*	*	*	*	*	*	*	*
▲ **Dec. Places:**	*	*	*	*	*	*	*	*	*	*
Mean:	*	*	*	*	106.219	88.156	56.281	44.469	110.267	110.533
Std. Deviation:	*	*	*	*	12.061	17.451	11.484	16.384	12.701	12.054
Std. Error:	*	*	*	*	2.132	3.085	2.030	2.896	2.319	2.201
Variance:	*	*	*	*	145.467	304.523	131.886	268.451	161.306	145.292
Coeff. of Variation:	*	*	*	*	11.355	19.795	20.405	36.845	11.518	10.905
Minimum:	S1	Lo	NG	R1	81	59	40	18	71	68
Maximum:	S15	Hi	Hi	R4	125	126	84	79	138	134
Range:	7.000	1.00	3.000	3.000	44.000	67.000	44.000	61.000	67.000	66.000
Count:	32	32	32	32	32	32	32	32	30	30
Missing Cells:	-	0	0	0	0	0	0	0	2	2
Sum:	*	*	*	*	3399.000	2821.000	1801.000	1423.000	3308.000	3316.000
Sum of Squares:	*	*	*	*	365547.000	258129.000	105451.000	71601.000	369440.000	370742.000
	S6	Lo	Mid	R1	115	71	40	18	71	68
	S9	Hi	Mid	R1	103	66	51	30	103	97
	S13	Hi	NG	R1	91	107	84	67	104	107
	S12	Lo	NG	R1	108	99	54	58	109	103
	S1	Hi	Hi	R1	100	85	44	45	111	104
	S13	Hi	Lo	R2	124	107	53	33	*	*
	S9	Hi	Hi	R2	125	74	54	42	*	*
	S15	Lo	Hi	R1	123	98	46	39	123	125
	S12	Lo	Lo	R2	97	82	48	38	97	109
	S9	Hi	Lo	R3	109	73	68	33	107	106
	S13	Hi	Hi	R3	123	59	44	26	138	115
	S1	Hi	NG	R2	97	111	45	64	115	114
	S15	Lo	NG	R2	94	120	67	67	96	119

Figure 47. ROM test data.

ROM
RAW SUBJECT DATA

	Subject	Strength	Glove	Run	Score_MCP	Score_PIP	Score_T1	Score_T2	Score_D2	Score_D3
	S1	Hi	Mid	R3	114	80	46	40	107	115
	S9	Hi	NG	R4	88	102	80	79	111	118
	S5	Lo	Lo	R1	103	70	57	61	126	113
	S6	Lo	Hi	R2	115	99	43	25	119	108
	S12	Lo	Hi	R3	121	90	60	28	113	101
	S6	Lo	Lo	R3	100	110	68	38	99	114
	S6	Lo	NG	R4	101	98	74	63	101	97
	S13	Hi	Mid	R4	123	77	62	36	118	107
	S1	Hi	Lo	R4	106	94	44	35	110	118
	S15	Lo	Mid	R3	108	90	47	42	109	116
	S11	Hi	Lo	R1	107	77	65	31	105	108
	S12	Lo	Mid	R4	107	81	54	36	118	126
	S11	Hi	Mid	R2	116	71	66	23	121	125
	S15	Lo	Lo	R4	98	109	63	65	99	108
	S11	Hi	NG	R3	96	126	70	63	114	118
	S11	Hi	Hi	R4	116	71	48	38	133	134
	S5	Lo	Mid	R2	83	85	54	42	121	96
	S5	Lo	NG	R3	81	63	55	75	100	112
	S5	Lo	Hi	R4	107	76	47	43	110	115

Figure 47. ROM test data (continued).

The ROM models indicated interactions with GS for MCP and PIP flexion as shown in figures 48 and 52, as well as for thumb opposition (T1) and planar (T2) motion, as shown in figures 56 and 60. The SNK tables show significant pairwise interactions.

ROM MODEL

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	185.281	185.281	1.299	.2979	Subject (Strength)
Subject (Strength)	6	855.938	142.656			
Glove	3	1954.094	651.365	10.092	.0004	Glove * Subject (Strength)
Glove * Strength	3	352.344	117.448	1.820	.1797	Glove * Subject (Strength)
Glove * Subject (Strength)	18	1161.812	64.545			
Residual	0	2.822E-17	*			

Dependent: Score_MCP

Figure 48. ROM MCP model.

Means Table
Effect: Glove
Dependent: Score_MCP

	Count	Mean	Std. Dev.	Std. Error
NG	8	94.500	8.194	2.897
Lo	8	105.500	8.635	3.053
Mid	8	108.625	12.082	4.272
Hi	8	116.250	8.795	3.110

Figure 49. ROM MCP means table for GS interactions.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_MCP
Significance level: .05

	Vs.	Diff.	Crit. diff.	
NG	Lo	11.000	8.436	S
	Mid	14.125	10.254	S
	Hi	21.750	11.362	S
Lo	Mid	3.125	8.436	
	Hi	10.750	10.254	S
Mid	Hi	7.625	8.436	

S = Significantly different at this level.

Figure 50. ROM MCP SNK for interactions with GS.

Interaction Plot
Effect: Glove
Dependent: Score_MCP

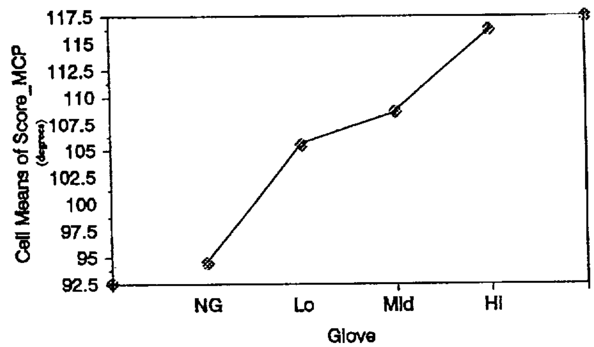


Figure 51. Graph of means versus GS for MCP ROM.

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	116.281	116.281	.0292	0.6081	Subject (Strength)
Subject (Strength)	6	2385.688	397.615			
Glove	3	3099.344	1033.115	7.321	0.0021	Glove * Subject (Strength)
Glove * Strength	3	1298.844	432.948	3.068	0.0543	Glove * Subject (Strength)
Glove * Subject (Strength)	18	2540.062	141.115			
Residual	0	5.294E-17	*			

Dependent: Score_PIP

Figure 52. ROM PIP model.

Means Table
Effect: Glove
Dependent: Score_PIP

	Count	Mean	Std. Dev.	Std. Error
NG	8	103.250	19.047	6.734
Lo	8	90.250	16.850	5.957
Mid	8	77.625	7.999	2.828
Hi	8	81.500	13.969	4.939

Figure 53. ROM PIP means table for GS interactions.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_PIP
Significance level: 0.05

	Vs.	Diff.	Crit. diff.	
Mid	Hi	3.875	12.474	
	Lo	12.625	15.162	
	NG	25.625	16.800	S
Hi	Lo	8.750	12.474	
	NG	21.750	15.162	S
Lo	NG	13.000	12.474	S

S = Significantly different at this level.

Figure 54. ROM PIP SNK for interactions with GS.

Interaction Plot
Effect: Glove
Dependent: Score_PIP

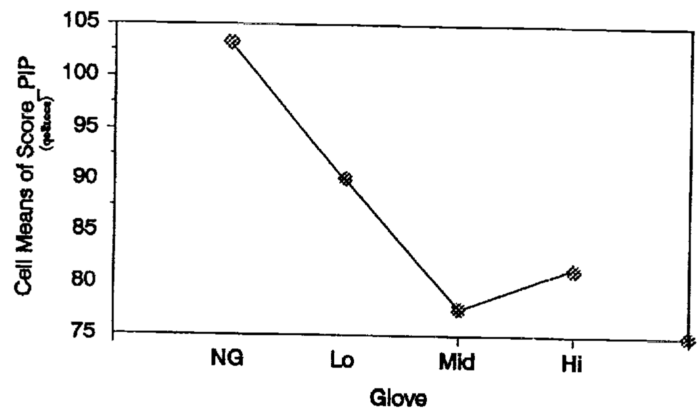


Figure 55. Graph of means versus GS for PIP ROM.

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	69.031	69.031	0.441	0.5311	Subject (Strength)
Subject (Strength)	6	938.188	156.365			
Glove	3	1436.594	478.865	5.796	0.0059	Glove * Subject (Strength)
Glove * Strength	3	157.594	52.531	.0636	0.6016	Glove * Subject (Strength)
Glove * Subject (Strength)	18	1487.062	82.615			
Residual	0	-2.090E-16	*			

Dependent: Score_T1

Figure 56. ROM T1 model.

Means Table
Effect: Glove
Dependent: Score_T1

	Count	Mean	Std. Dev.	Std. Error
NG	8	66.125	13.664	4.831
Lo	8	58.250	9.223	3.261
Mid	8	52.500	8.519	3.012
Hi	8	48.250	5.874	2.077

Figure 57. ROM T1 means table for GS interactions.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_T1
Significance level: .05

	Versus	Diff.	Crit. diff.	
Hi	Mid	4.250	9.544	
	Lo	10.000	11.601	
	NG	17.875	12.854	S
Mid	Lo	5.750	9.544	
	NG	13.625	11.601	S
Lo	NG	7.875	9.544	

S = Significantly different at this level.

Figure 58. ROM T1 SNK for interactions with GS.

Interaction Plot
Effect: Glove
Dependent: Score_T1

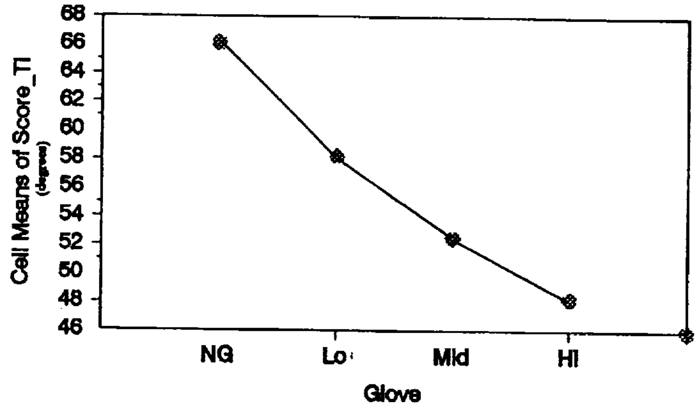


Figure 59. Graph of means versus GS for T1 ROM.

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	87.781	87.781	.416	.5426	Subject (Strength)
Subject (Strength)	6	1264.938	210.823			
Glove	3	5713.094	1904.365	50.647	.0001	Glove * Subject (Strength)
Glove * Strength	3	579.344	193.115	5.136	.0097	Glove * Subject (Strength)
Glove * Subject (Strength)	18	676.812	37.601			
Residual	0	1.379E-16	•			

Dependent: Score_T2

Figure 60. ROM T2 model.

Means Table
Effect: Glove
Dependent: Score_T2

	Count	Mean	Std. Dev.	Std. Error
NG	8	67.000	6.866	2.428
Lo	8	41.750	13.382	4.731
Mid	8	33.375	8.959	3.168
Hi	8	35.750	8.137	2.877

Figure 61. ROM T2 means table for GS interactions.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_T2
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Mid	Hi	2.375	6.439	
	Lo	8.375	7.826	S
	NG	33.625	8.672	S
Hi	Lo	6.000	6.439	
	NG	31.250	7.826	S
Lo	NG	25.250	6.439	S

S = Significantly different at this level.

Figure 62. ROM T2 SNK for interactions with GS.

Interaction Plot
Effect: Glove
Dependent: Score_T2

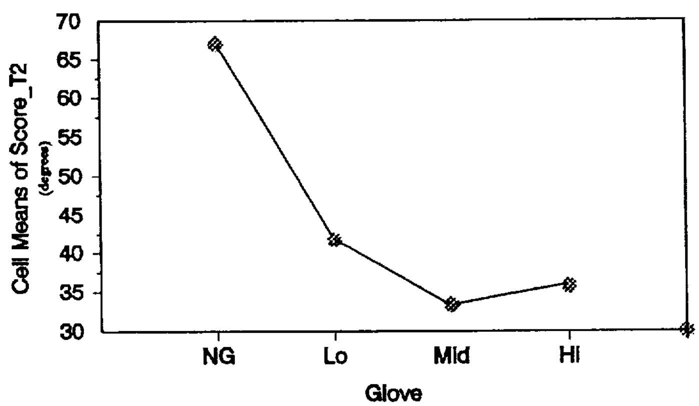


Figure 63. Graph of means versus GS for T2 ROM.

Means Table
Effect: Glove * Strength
Dependent: Score_T2

	Count	Mean	Std. Dev.	Std. Error
NG, Lo	4	65.750	7.182	3.591
NG, Hi	4	68.250	7.365	3.683
Lo, Lo	4	50.500	14.526	7.263
Lo, Hi	4	33.000	1.633	.816
Mid, Lo	4	34.500	11.358	5.679
Mid, Hi	4	32.250	7.411	3.705
Hi, Lo	4	33.750	8.617	4.308
Hi, Hi	4	37.750	8.342	4.171

Figure 64. ROM T2 means table for GS interactions.

Interaction Plot
Effect: Glove * Strength
Dependent: Score_T2

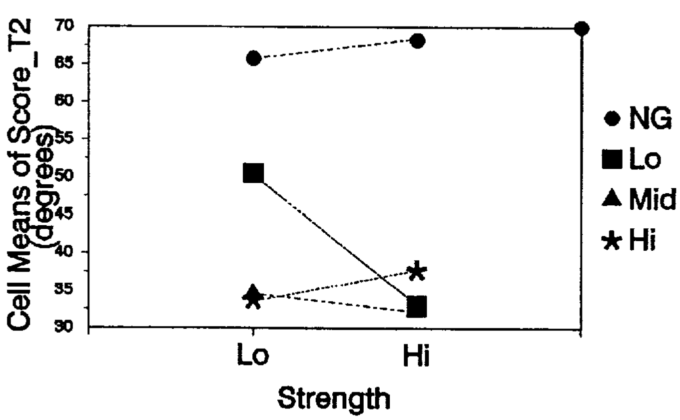


Figure 65. Graph of T2 ROM means versus strength for GS.

Digits 2 and 3 ROM Model

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	380.001	380.001	2.372	0.1744	Subject (Strength)
Subject (Strength)	6	961.116	160.186			
Glove	3	975.450	325.150	2.247	0.1222	Glove * Subject (Strength)
Glove * Strength	3	45.850	15.283	0.106	0.9556	Glove * Subject (Strength)
Glove * Subject (Strength)	16	2315.450	144.716			
Residual	0	-3.161E-14	*			

Dependent: Score_D2

NOTE: 2 rows have been excluded from calculations because of missing values.

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	198.860	198.860	0.948	0.3679	Subject (Strength)
Subject (Strength)	6	1258.940	209.823			
Glove	3	240.553	80.184	0.536	0.6644	Glove * Subject (Strength)
Glove * Strength	3	120.876	40.292	0.269	0.8466	Glove * Subject (Strength)
Glove * Subject (Strength)	16	2394.237	149.640			
Residual	0	2.415E-15	*			

Dependent: Score_D3

NOTE: 2 rows have been excluded from calculations because of missing values.

Figure 66. ROM digits 2 and 3 model.

No significant interactions with GS occurred for the index and middle finger tests as can be seen by the P-values in figure 66.

ROM Thumb Planar Motion: Glove * Strength

	32.25	33	33.75	34.5	37.75	50.5	65.75	68.25
32.25	0	0.75	1.5	2.25	5.5	18.25	33.5	36
33		0	0.75	1.5	4.75	17.5	32.75	35.25
33.75			0	0.75	4	16.75	32	34.5
34.5				0	3.25	16	31.25	33.75
37.75					0	12.75	28	30.5
50.5						0	15.25	17.75
65.75							0	2.5
68.25								0
'alpha=0.05	'df=18		q	MS	F12=MS/n	sqrt(f12)	CD	
'r=2	2.97		2.97	37.601	9.40025	3.065983	9.105969	
'r=3	3.61		3.61	37.601	9.40025	3.065983	11.0682	
'r=4	4.00		4.00	37.601	9.40025	3.065983	12.26393	
'r=5	4.28		4.28	37.601	9.40025	3.065983	13.12241	
'r=6	4.49		4.49	37.601	9.40025	3.065983	13.76626	
'r=7	4.67		4.67	37.601	9.40025	3.065983	14.31814	
'r=8	4.82		4.82	37.601	9.40025	3.065983	14.77804	

Figure 67. ROM T2 SNK calculation for Glove * Strength.

Grip Strength

Grip strength effects due to glove were significant, as were effects due to the number of attempts in a run. In the grip test, there were five attempts per run. Grip strength test data is shown in figure 68. Score refers to force in pounds (lb).

GRIP STRENGTH RAW SUBJECT DATA						
	Subject	**Strength**	**Glove**	**Run**	**Attempt**	**Score**
• Type:	Category	Category	Category	Category	Category	Real
• Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
•Class:	Nominal	Nominal	Nominal	Nominal	Nominal	Continuous
• Format:	*	*	*	*	*	Free Format Fl...
• Dec. Places:	*	*	*	*	*	3
Mean:	*	*	*	*	*	28.859
Std. Deviation:	*	*	*	*	*	13.229
Std. Error:	*	*	*	*	*	1.046
Variance:	*	*	*	*	*	175.001
Coeff. of Variation:	*	*	*	*	*	45.839
Minimum:	s1	Lo	NG	1	1	7.000
Maximum:	S15	Hi	Hi	4	5	59.000
Range:	7.000	1.000	3.000	3.000	4.000	52.000
Count:	160	160	160	160	160	160
Missing Cells:	0	0	0	0	0	0
Sum:	*	*	*	*	*	4617.500
Sum of Squares:	*	*	*	*	*	161083.250
	S1	Hi	Hi	1	1	42.000
	S1	Hi	Hi	1	2	29.000
	S1	Hi	Hi	1	3	28.000
	S1	Hi	Hi	1	4	30.000
	S1	Hi	Hi	1	5	28.000
	S1	Hi	NG	2	1	50.000
	S1	Hi	NG	2	2	47.000
	S1	Hi	NG	2	3	44.000
	S1	Hi	NG	2	4	48.000
	S1	Hi	NG	2	5	44.000
	S1	Hi	Mid	3	1	38.000
	S1	Hi	Mid	3	2	38.000
	S1	Hi	Mid	3	3	35.000
	S1	Hi	Mid	3	4	36.000
	S1	Hi	Mid	3	5	42.000
	S1	Hi	Lo	4	1	48.000
	S1	Hi	Lo	4	2	44.000
	S1	Hi	Lo	4	3	46.000
	S1	Hi	Lo	4	4	47.000
	S1	Hi	Lo	4	5	40.000
	S9	Hi	Mid	1	1	34.000
	S9	Hi	Mid	1	2	28.000
	S9	Hi	Mid	1	3	26.000
	S9	Hi	Mid	1	4	28.000
	S9	Hi	Mid	1	5	24.000
	S9	Hi	Hi	2	1	26.000
	S9	Hi	Hi	2	2	26.000
	S9	Hi	Hi	2	3	27.000
	S9	Hi	Hi	2	4	26.000
	S9	Hi	Hi	2	5	27.000
	S9	Hi	Lo	3	1	35.000
	S9	Hi	Lo	3	2	36.000
	S9	Hi	Lo	3	3	32.000
	S9	Hi	Lo	3	4	31.000
	S9	Hi	Lo	3	5	28.000

Figure 68. Grip strength test data.

GRIP STRENGTH
RAW SUBJECT DATA

Subject	Strength	Glove	Run	Attempt	Score
S9	Hi	NG	4	1	57.000
S9	Hi	NG	4	2	59.000
S9	Hi	NG	4	3	54.000
S9	Hi	NG	4	4	49.000
S9	Hi	NG	4	5	51.000
S11	Hi	Lo	1	1	39.000
S11	Hi	Lo	1	2	37.000
S11	Hi	Lo	1	3	34.000
S11	Hi	Lo	1	4	32.000
S11	Hi	Lo	1	5	31.000
S11	Hi	Mid	2	1	30.000
S11	Hi	Mid	2	2	29.000
S11	Hi	Mid	2	3	29.000
S11	Hi	Mid	2	4	27.000
S11	Hi	Mid	2	5	26.000
S11	Hi	NG	3	1	58.000
S11	Hi	NG	3	2	56.000
S11	Hi	NG	3	3	59.000
S11	Hi	NG	3	4	56.000
S11	Hi	NG	3	5	55.000
S11	Hi	Hi	4	1	24.000
S11	Hi	Hi	4	2	24.000
S11	Hi	Hi	4	3	22.000
S11	Hi	Hi	4	4	24.000
S11	Hi	Hi	4	5	21.000
S13	Hi	NG	1	1	58.000
S13	Hi	NG	1	2	56.000
S13	Hi	NG	1	3	56.000
S13	Hi	NG	1	4	52.000
S13	Hi	NG	1	5	52.000
S13	Hi	Lo	2	1	36.000
S13	Hi	Lo	2	2	34.000
S13	Hi	Lo	2	3	33.000
S13	Hi	Lo	2	4	34.000
S13	Hi	Lo	2	5	33.000
S13	Hi	Hi	3	1	28.000
S13	Hi	Hi	3	2	8.000
S13	Hi	Hi	3	3	10.000
S13	Hi	Hi	3	4	8.000
S13	Hi	Hi	3	5	8.000
S13	Hi	Mid	4	1	34.000
S13	Hi	Mid	4	2	34.000
S13	Hi	Mid	4	3	32.000
S13	Hi	Mid	4	4	32.000
S13	Hi	Mid	4	5	30.000
S5	Lo	Lo	1	1	32.000
S5	Lo	Lo	1	2	33.000
S5	Lo	Lo	1	3	31.000
S5	Lo	Lo	1	4	30.000
S5	Lo	Lo	1	5	29.000
S5	Lo	Mid	2	1	27.000
S5	Lo	Mid	2	2	28.00
S5	Lo	Mid	2	3	29.000
S5	Lo	Mid	2	4	24.000
S5	Lo	Mid	2	5	22.000
S5	Lo	NG	3	1	41.000
S5	Lo	NG	3	2	40.000
S5	Lo	NG	3	3	38.000
S5	Lo	NG	3	4	33.000
S5	Lo	NG	3	5	37.000
S5	Lo	Hi	4	1	18.000
S5	Lo	Hi	4	2	17.000
S5	Lo	Hi	4	3	21.000
S5	Lo	Hi	4	4	22.000

Figure 68. Grip strength test data (continued).

	Subject	Strength	Glove	Run	Attempt	Score
	GRIP STRENGTH RAW SUBJECT DATA					
	Subject	**Strength**	**Glove**	**Run**	**Attempt**	**Score**
	S5	Lo	Hi	4	5	21.000
	S12	Lo	NG	1	1	36.000
	S12	Lo	NG	1	2	36.000
	S12	Lo	NG	1	3	36.000
	S12	Lo	NG	1	4	37.000
	S12	Lo	NG	1	5	33.000
	S12	Lo	Lo	2	1	28.000
	S12	Lo	Lo	2	2	31.000
	S12	Lo	Lo	2	3	28.000
	S12	Lo	Lo	2	4	28.000
	S12	Lo	Lo	2	5	28.000
	S12	Lo	Hi	3	1	18.000
	S12	Lo	Hi	3	2	17.000
	S12	Lo	Hi	3	3	18.000
	S12	Lo	Hi	3	4	12.000
	S12	Lo	Hi	3	5	15.000
	S12	Lo	Mid	4	1	20.000
	S12	Lo	Mid	4	2	24.000
	S12	Lo	Mid	4	3	24.000
	S12	Lo	Mid	4	4	24.000
	S12	Lo	Mid	4	5	24.000
	S6	Lo	Mid	1	1	18.000
	S6	Lo	Mid	1	2	20.000
	S6	Lo	Mid	1	3	18.000
	S6	Lo	Mid	1	4	18.000
	S6	Lo	Mid	1	5	17.000
	S6	Lo	Hi	2	1	12.000
	S6	Lo	Hi	2	2	13.000
	S6	Lo	Hi	2	3	12.000
	S6	Lo	Hi	2	4	12.000
	S6	Lo	Hi	2	5	11.000
	S6	Lo	Lo	3	1	17.000
	S6	Lo	Lo	3	2	25.000
	S6	Lo	Lo	3	3	23.000
	S6	Lo	Lo	3	4	20.000
	S6	Lo	Lo	3	5	23.000
	S6	Lo	NG	4	1	38.000
	S6	Lo	NG	4	2	30.000
	S6	Lo	NG	4	3	30.000
	S6	Lo	NG	4	4	28.000
	S6	Lo	NG	4	5	31.000
	S15	Lo	Hi	1	1	8.000
	S15	Lo	Hi	1	2	9.000
	S15	Lo	Hi	1	3	7.000
	S15	Lo	Hi	1	4	8.000
	S15	Lo	Hi	1	5	8.000
	S15	Lo	NG	2	1	20.000
	S15	Lo	NG	2	2	21.000
	S15	Lo	NG	2	3	18.000
	S15	Lo	NG	2	4	17.000
	S15	Lo	NG	2	5	12.000
	S15	Lo	Mid	3	1	9.000
	S15	Lo	Mid	3	2	8.000
	S15	Lo	Mid	3	3	9.000
	S15	Lo	Mid	3	4	9.000
	S15	Lo	Mid	3	5	9.000
	S15	Lo	Lo	4	1	11.000
	S15	Lo	Lo	4	2	10.500
	S15	Lo	Lo	4	3	9.000
	S15	Lo	Lo	4	4	10.000
	S15	Lo	Lo	4	5	10.000

Figure 68. Grip strength test data (continued).

MODEL OF GRIP DATA:
INTERACTION WITH GLOVE

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	8417.252	8417.252	12.424	.0124	Subject (Strength)
Subject (Strength)	6	4064.847	677.474			
Glove	3	11439.467	3813.156	37.887	.0001	Glove * Subject (Strength)
Glove * Strength	3	942.080	314.027	3.120	0.0518	Glove * Subject (Strength)
Glove * Subject (Strength)	18	1811.641	100.647			
Attempt	4	277.594	69.398	18.817	.0001	Attempt * Subject (Strength)
Attempt * Strength	4	110.944	27.736	7.521	.0004	Attempt * Subject (Strength)
Attempt * Subject (Strength)	24	88.513	3.688			
Attempt * Glove	12	83.431	6.953	.983	.4732	Attempt * Glove * Subject (Strength)
Attempt * Glove * Strength	12	80.131	6.679	.944	.5090	Attempt * Glove * Subject (Strength)
Attempt * Glove * Subject	72	509.187	7.072			
Residual	0	1.459E-15	*			

Dependent: Score

MODEL OF GRIP DATA:
EFFECTS OVER ATTEMPTS INTERACTIONS WITH STRENGTH

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	8417.252	8417.252	12.424	.0124	Subject (Strength)
Subject (Strength)	6	4064.847	677.474			
Run	3	227.517	75.839	.099	.9598	Run * Subject (Strength)
Run * Strength	3	126.530	42.177	0.055	.9825	Run * Subject (Strength)
Run * Subject (Strength)	18	13839.141	768.841			
Attempt	4	277.594	69.398	18.817	.0001	Attempt * Subject (Strength)
Attempt * Strength	4	110.944	27.736	7.521	.0004	Attempt * Subject (Strength)
Attempt * Subject (Strength)	24	88.513	3.688			
Run * Attempt	12	59.881	4.990	.694	.7519	Run * Attempt * Subject (Strength)
Run * Attempt * Strength	12	95.181	7.932	1.103	.3711	Run * Attempt * Subject (Strength)
Run * Attempt * Subject	72	517.687	7.190			
Residual	0	3.192E-15	*			

Dependent: Score

Figure 69. Grip strength models.

Means Table
Effect: Strength
Dependent: Score

	Count	Mean	Std. Dev.	Std. Error
Lo	80	21.606	9.455	10.057
Hi	80	36.112	12.501	1.398

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Score
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Lo	Hi	14.506	10.069	S

S = Significantly different at this level.

Figure 70. Grip strength SNK.

Means Table
Effect: Attempt
Dependent: Score

	Count	Mean	Std. Dev.	Std. Error
1	32	30.938	14.004	2.476
2	32	29.609	13.584	2.401
3	32	28.688	13.297	2.351
4	32	27.875	12.936	2.287
5	32	27.188	12.800	2.263

Figure 71. Grip means table for Attempt.

Student-Newman-Keuls
Effect: Attempt
Error term: Type I sum of squares for Attempt * Subject Strength
Dependent: Score
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
5	4	.688	.991	
	3	1.500	1.198	S
	2	2.422	1.324	S
	1	3.750	1.416	S
4	3	.812	.991	
	2	1.734	1.198	S
	1	3.062	1.324	S
3	2	.922	.991	
	1	2.250	1.198	S
2	1	1.328	.991	S

S = Significantly different at this level.

Figure 72. Grip SNK for Attempt.

Interaction Plot
Effect: Attempt
Dependent: Score

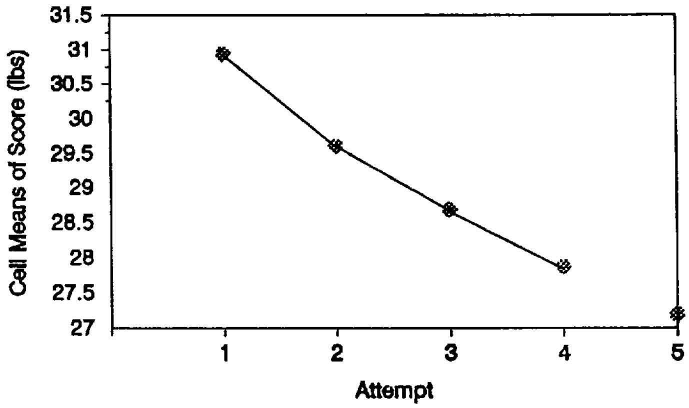


Figure 73. Grip mean versus Attempt.

Means Table
Effect: Attempt * Strength
Dependent: Score

	Count	Mean	Std. Dev.	Std. Error
1,Lo	16	22.062	10.459	2.615
1,Hi	16	39.812	11.309	2.827
2,Lo	16	22.656	9.870	2.468
2,Hi	16	36.562	13.446	3.362
3,Lo	16	21.938	9.657	2.414
3,Hi	16	35.438	13.226	3.307
4,Lo	16	20.750	9.015	2.254
4,Hi	16	35.000	12.501	3.125
5,Lo	16	20.625	9.280	2.320
5,Hi	16	33.750	12.673	3.168

Figure 74. Grip means table for Attempt * Strength.

Interaction Plot
Effect: Attempt * Strength
Dependent: Score

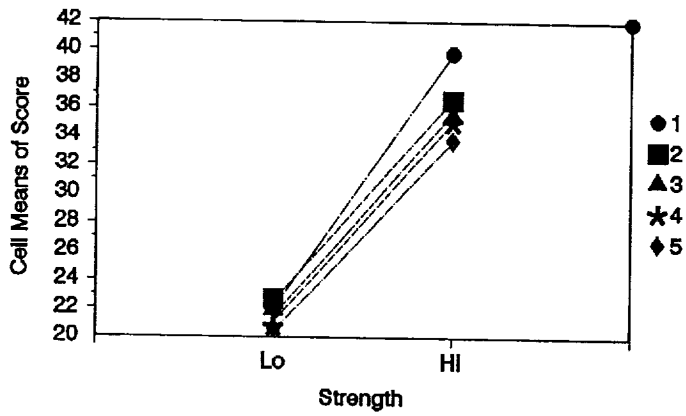


Figure 75. Grip mean versus strength for Attempt * Strength.

Grip: Attempt * Strength

	20.625	20.375	21.938	22.062	22.656	33.75	35	35.438	36.562	39.812
20.625	0	0.125	1.313	1.437	2.031	13.125	14.375	14.813	15.937	19.187
20.75		0	1.188	1.312	1.906	13	14.25	14.688	15.812	19.062
21.938			0	.0124	.0718	11.812	13.062	13.5	14.624	17.874
22.062				0	0.594	11.688	12.938	13.376	14.5	17.75
22.656					0	11.094	12.344	12.782	13.906	17.156
33.75						0	1.25	1.688	2.812	6.062
35							0	.0438	1.562	4.374
35.438								0	1.124	4.374
36.562									0	3.25
39.812										0
'alpha=0.05	'df=24		q	MS	F12=MS/n	sqrt(f12)	CD			
'r=2	2.92		2.92	3.6888	.0922	0.960208	2.803808			
'r=3	3.53		3.53	3.6888	.0922	0.960208	3.389535			
'r=4	3.90		3.90	3.6888	.0922	0.960208	3.744812			
'r=5	4.17		4.17	3.6888	.0922	0.960208	4.004069			
'r=6	4.37		4.37	3.6888	.0922	0.960208	4.19611			
'r=7	4.54		4.54	3.6888	.0922	0.960208	4.359346			
'r=8	4.68		4.68	3.6888	.0922	0.960208	4.493775			
'r=9	4.81		4.81	3.6888	.0922	0.960208	4.618602			
'r=10	4.92		4.92	3.6888	.0922	0.960208	4.724225			

Figure 76. Grip SNK calculated for Attempt * Strength.

Means Table
Effect: Glove
Dependent: Score

	Count	Mean	Std. Dev.	Std. Error
NG	40	41.825	13.264	2.097
Lo	40	29.663	9.966	1.576
Mid	40	25.325	8.636	1.366
Hi	40	18.625	8.384	1.326

Figure 77. Grip means for interactions with GS.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score
Significance level: 0.05

	Versus	Diff.	Crit. diff.
Hi	Mid	6.700	4.711
	Lo	11.038	5.726
	NG	23.200	6.345
Mid	Lo	4.337	4.711
	NG	16.500	5.726
Lo	NG	12.163	4.711

S = Significantly different at this level.

Figure 78. Grip SNK for GS interactions.

Interaction Plot
Effect: Glove
Dependent: Score
With 95% Confidence error bars.

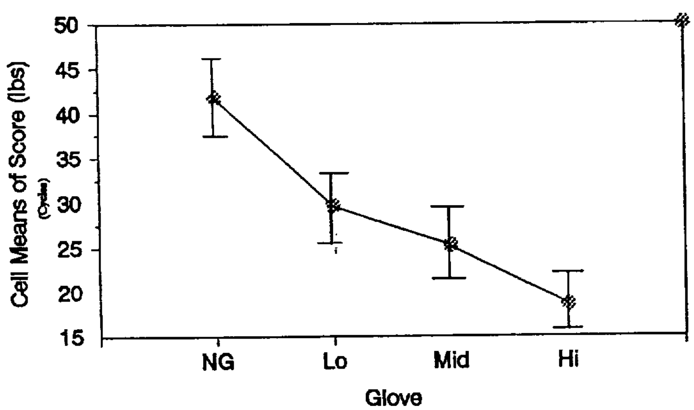


Figure 79. Grip means versus GS.

Pinch Strength

Lateral pinch strength was tested. Five attempts were done per run. Score refers to force in pounds. Data are shown in figure 80.

PINCH STRENGTH RAW SUBJECT DATA						
	Subject	**Strength**	**Glove**	**Run**	**Attempt**	**Score**
• Type:	Category	Category	Category	Category	Category	Real
• Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
• Class:	Nominal	Nominal	Nominal	Nominal	Nominal	Continuous
• Format:	*	*	*	*	*	Free Format Fl...
• Dec. Places:	*	*	*	*	*	1
Mean:	*	*	*	*	*	7.9
Std. Deviation:	*	*	*	*	*	2.1
Std. Error:	*	*	*	*	*	.2
Variance:	*	*	*	*	*	4.5
Coeff. of Variation:	*	*	*	*	*	27.1
Minimum:	S1	Lo	NG	R1	A1	4.0
Maximum:	S15	Hi	Hi	R4	A5	13.0
Range:	7.000	1.000	3.000	3.000	4.000	9.0
Count:	160	160	160	160	160	160
Missing Cells:	0	0	0	0	0	0
Sum:	*	*	*	*	*	1258.6
Sum of Squares:	*	*	*	*	*	10621.8
	S1	Hi	Hi	R1	A1	8.5
	S1	Hi	Hi	R1	A2	8.0
	S1	Hi	Hi	R1	A3	8.5
	S1	Hi	Hi	R1	A4	8.0
	S1	Hi	Hi	R1	A5	7.5
	S1	Hi	NG	R2	A1	8.0
	S1	Hi	NG	R2	A2	8.7
	S1	Hi	NG	R2	A3	8.6
	S1	Hi	NG	R2	A4	8.5
	S1	Hi	NG	R2	A5	8.5
	S1	Hi	Mid	R3	A1	9.0
	S1	Hi	Mid	R3	A2	8.5
	S1	Hi	Mid	R3	A3	7.4
	S1	Hi	Mid	R3	A4	8.3
	S1	Hi	Mid	R3	A5	8.5
	S1	Hi	Lo	R4	A1	9.5
	S1	Hi	Lo	R4	A2	7.9
	S1	Hi	Lo	R4	A3	9.0
	S1	Hi	Lo	R4	A4	9.0
	S1	Hi	Lo	R4	A5	8.9
	S9	Hi	Mid	R1	A1	11.5
	S9	Hi	Mid	R1	A2	11.0
	S9	Hi	Mid	R1	A3	11.5
	S9	Hi	Mid	R1	A4	10.0
	S9	Hi	Mid	R1	A5	9.5
	S9	Hi	Hi	R2	A1	8.5
	S9	Hi	Hi	R2	A2	9.7
	S9	Hi	Hi	R2	A3	9.5
	S9	Hi	Hi	R2	A4	8.5
	S9	Hi	Hi	R2	A5	8.5
	S9	Hi	Lo	R3	A1	11.0
	S9	Hi	Lo	R3	A2	10.6
	S9	Hi	Lo	R3	A3	11.0
	S9	Hi	Lo	R3	A4	10.7
	S9	Hi	Lo	R3	A5	10.6
	S9	Hi	NG	R4	A1	9.5
	S9	Hi	NG	R4	A2	9.3
	S9	Hi	NG	R4	A3	9.5

Figure 80. Pinch strength test data.

PINCH STRENGTH
RAW SUBJECT DATA

Subject	Strength	Glove	Run	Attempt	Score
S9	Hi	NG	R4	A4	9.0
S9	Hi	NG	R4	A5	9.0
S11	Hi	Lo	R1	A1	9.5
S11	Hi	Lo	R1	A2	9.0
S11	Hi	Lo	R1	A3	8.6
S11	Hi	Lo	R1	A4	9.1
S11	Hi	Lo	R1	A5	9.0
S11	Hi	Mid	R2	A1	9.0
S11	Hi	Mid	R2	A2	9.3
S11	Hi	Mid	R2	A3	8.5
S11	Hi	Mid	R2	A4	9.3
S11	Hi	Mid	R2	A5	9.0
S11	Hi	NG	R3	A1	8.3
S11	Hi	NG	R3	A2	8.4
S11	Hi	NG	R3	A3	9.0
S11	Hi	NG	R3	A4	8.6
S11	Hi	NG	R3	A5	9.4
S11	Hi	Hi	R4	A1	7.1
S11	Hi	Hi	R4	A2	8.0
S11	Hi	Hi	R4	A3	8.0
S11	Hi	Hi	R4	A4	8.0
S11	Hi	Hi	R4	A5	7.9
S13	Hi	NG	R1	A1	12.0
S13	Hi	NG	R1	A2	11.0
S13	Hi	NG	R1	A3	10.5
S13	Hi	NG	R1	A4	11.0
S13	Hi	NG	R1	A5	9.5
S13	Hi	Lo	R2	A1	13.0
S13	Hi	Lo	R2	A2	10.0
S13	Hi	Lo	R2	A3	10.0
S13	Hi	Lo	R2	A4	11.5
S13	Hi	Lo	R2	A5	11.5
S13	Hi	Hi	R3	A1	10.5
S13	Hi	Hi	R3	A2	8.0
S13	Hi	Hi	R3	A3	10.0
S13	Hi	Hi	R3	A4	9.0
S13	Hi	Hi	R3	A5	9.0
S13	Hi	Mid	R4	A1	11.0
S13	Hi	Mid	R4	A2	9.0
S13	Hi	Mid	R4	A3	12.1
S13	Hi	Mid	R4	A4	10.5
S13	Hi	Mid	R4	A5	10.5
S5	Lo	Lo	R1	A1	7.0
S5	Lo	Lo	R1	A2	7.0
S5	Lo	Lo	R1	A3	7.3
S5	Lo	Lo	R1	A4	7.3
S5	Lo	Lo	R1	A5	6.2
S5	Lo	Mid	R2	A1	6.6
S5	Lo	Mid	R2	A2	7.1
S5	Lo	Mid	R2	A3	6.4
S5	Lo	Mid	R2	A4	6.1
S5	Lo	Mid	R2	A5	6.0
S5	Lo	NG	R3	A1	6.4
S5	Lo	NG	R3	A2	6.7
S5	Lo	NG	R3	A3	6.9
S5	Lo	NG	R3	A4	7.1
S5	Lo	NG	R3	A5	7.4
S5	Lo	Hi	R4	A1	4.7
S5	Lo	Hi	R4	A2	4.0
S5	Lo	Hi	R4	A3	4.6
S5	Lo	Hi	R4	A4	4.8
S5	Lo	Hi	R4	A5	4.1
S12	Lo	NG	R1	A1	10.0
S12	Lo	NG	R1	A2	10.0
S12	Lo	NG	R1	A3	9.5

Figure 80. Pinch strength test data (continued).

PINCH STRENGTH RAW SUBJECT DATA						
	Subject	Strength	Glove	Run	Attempt	Score
	S12	Lo	NG	R1	A4	9.5
	S12	Lo	NG	R1	A5	9.0
	S12	Lo	Lo	R2	A1	11.5
	S12	Lo	Lo	R2	A2	11.0
	S12	Lo	Lo	R2	A3	10.5
	S12	Lo	Lo	R2	A4	10.0
	S12	Lo	Lo	R2	A5	9.5
	S12	Lo	Hi	R3	A1	6.5
	S12	Lo	Hi	R3	A2	7.1
	S12	Lo	Hi	R3	A3	6.7
	S12	Lo	Hi	R3	A4	6.5
	S12	Lo	Hi	R3	A5	6.0
	S12	Lo	Mid	R4	A1	7.5
	S12	Lo	Mid	R4	A2	7.7
	S12	Lo	Mid	R4	A3	7.4
	S12	Lo	Mid	R4	A4	7.5
	S12	Lo	Mid	R4	A5	7.4
	S6	Lo	Mid	R1	A1	6.0
	S6	Lo	Mid	R1	A2	5.0
	S6	Lo	Mid	R1	A3	6.0
	S6	Lo	Mid	R1	A4	5.0
	S6	Lo	Mid	R1	A5	5.0
	S6	Lo	Hi	R2	A1	6.0
	S6	Lo	Hi	R2	A2	5.7
	S6	Lo	Hi	R2	A3	4.5
	S6	Lo	Hi	R2	A4	4.5
	S6	Lo	Hi	R2	A5	5.0
	S6	Lo	Lo	R3	A1	6.0
	S6	Lo	Lo	R3	A2	6.3
	S6	Lo	Lo	R3	A3	6.0
	S6	Lo	Lo	R3	A4	6.0
	S6	Lo	Lo	R3	A5	6.2
	S6	Lo	NG	R4	A1	7.0
	S6	Lo	NG	R4	A2	6.8
	S6	Lo	NG	R4	A3	6.7
	S6	Lo	NG	R4	A4	6.6
	S6	Lo	NG	R4	A5	6.9
	S15	Lo	Hi	R1	A1	4.5
	S15	Lo	Hi	R1	A2	4.5
	S15	Lo	Hi	R1	A3	5.0
	S15	Lo	Hi	R1	A4	5.0
	S15	Lo	Hi	R1	A5	4.0
	S15	Lo	NG	R2	A1	4.5
	S15	Lo	NG	R2	A2	6.3
	S15	Lo	NG	R2	A3	6.4
	S15	Lo	NG	R2	A4	6.1
	S15	Lo	NG	R2	A5	6.0
	S15	Lo	Mid	R3	A1	4.5
	S15	Lo	Mid	R3	A2	4.5
	S15	Lo	Mid	R3	A3	4.7
	S15	Lo	Mid	R3	A4	4.9
	S15	Lo	Mid	R3	A5	4.9
	S15	Lo	Lo	R4	A1	4.5
	S15	Lo	Lo	R4	A2	4.1
	S15	Lo	Lo	R4	A3	4.4
	S15	Lo	Lo	R4	A4	4.5
	S15	Lo	Lo	R4	A5	4.3

Figure 80. Pinch strength test data (continued).

PINCH GRIP MODEL

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	360.000	360.000	10.708	0.0170	Subject (Strength)
Subject (Strength)	6	201.725	33.621			
Glove	3	62.997	20.999	9.782	0.0005	Glove * Subject (Strength)
Glove * Strength	3	14.765	4.922	2.293	0.1126	Glove * Subject (Strength)
Glove * Subject (Strength)	18	38.639	2.147			
Attempt	4	3.873	0.968	1.725	0.1774	Attempt * Subject (Strength)
Attempt * Strength	4	1.627	0.407	0.725	0.5838	Attempt * Subject (Strength)
Attempt * Subject (Strength)	24	13.473	0.561			
Attempt * Glove	12	3.140	0.262	1.008	0.4506	Attempt * Glove * Subject (Strength)
Attempt * Glove * Strength	12	2.376	0.198	0.763	0.6855	Attempt * Glove * Subject (Strength)
Attempt * Glove * Subject	72	18.683	0.259			
Residual	0	1.623E-15	*			

Dependent: Score

Figure 81. Pinch grip model, interactions with GS and Attempt.

PINCH GRIP MODEL:
EFFECTS OVER ATTEMPTS INTERACTIONS WITH STRENGTH

Type I Sums of Squares

Source of Variance	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	360.000	360.00	10.708	0.0170	Subject (Strength)
Subject (Strength)	6	201.725	33.621			
Run	3	16.151	5.384	1.017	0.4081	Run * Subject (Strength)
Run * Strength	3	4.996	1.665	0.315	0.8145	Run * Subject (Strength)
Run * Subject (Strength)	18	95.253	5.292			
Attempt	4	3.873	0.968	1.725	0.1774	Attempt * Subject (Strength)
Attempt * Strength	4	1.627	0.407	0.725	0.5838	Attempt * Subject (Strength)
Attempt * Subject (Strength)	24	13.473	0.561			
Run * Attempt	12	5.863	0.489	2.227	0.0188	Run * Attempt * Subject (Strength)
Run * Attempt * Strength	12	2.542	0.212	0.966	0.4892	Run * Attempt * Subject (Strength)
Run * Attempt * Subject	72	15.794	0.219			
Residual	0	1.742E-15	*			

Dependent: Score

Figure 82. Model of pinch performance over Run, Attempts.

Means Table
Effect: Strength
Dependent: Score

	Count	Mean	Std. Dev.	Std. Error
Lo	80	6.366	1.756	0.196
Hi	80	9.366	1.220	0.136

Figure 83. Pinch means table for strength interactions.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Score
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Lo	Hi	3.000	2.243	S

S = Significantly different at this level.

Figure 84. Pinch SNK for strength interactions.

Means Table
Effect: Strength
Dependent: Score

	Count	Mean	Std. Dev.	Std. Error
R1,A1	8	8.625	2.642	.934
R1,A2	8	8.188	2.535	.896
R1,A3	8	8.362	2.197	.777
R1,A4	8	8.112	2.231	.789
R1,A5	8	7.463	2.161	.764
R1,A1	8	8.387	2.816	.996
R1,A2	8	8.475	1.899	.672
R1,A3	8	80.050	2.086	.738
R1,A4	8	8.062	2.326	.822
R1,A5	8	8.000	2.171	.768
R1,A1	8	7.775	2.299	.813
R1,A2	8	7.512	1.809	.640
R1,A3	8	7.713	2.121	.750
R1,A4	8	7.637	1.865	.660
R1,A5	8	7.750	1.952	.690
R1,A1	8	7.600	2.312	.817
R1,A2	8	7.100	2.034	.719
R1,A3	8	7.713	2.563	.906
R1,A4	8	7.487	2.099	.742
R1,A5	8	7.313	2.155	.762

Figure 85. Pinch means table for Run * Attempt interactions.

Interaction Plot
Effect: Run * Attempt
Dependent: Score

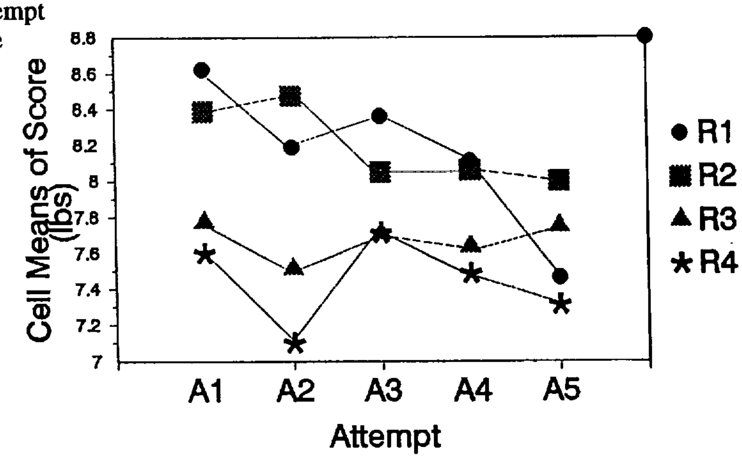


Figure 86. Graph of means versus Attempt for Runs.

Means Table
Effect: Glove
Dependent: Score

	Count	Mean	Std. Dev.	Std. Error
NG	40	8.302	1.638	0.259
Lo	40	8.475	2.389	0.378
Mid	40	7.828	2.190	0.346
Hi	40	6.860	1.921	0.304

Figure 87. Pinch means table for interactions with GS.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Hi	Mid	0.967	0.688	S
	NG	1.442	0.836	S
	Lo	1.615	0.927	S
Mid	NG	0.475	0.688	
	Lo	0.648	0.836	
NG	Lo	0.173	0.688	

S = Significantly different at this level.

Figure 88. Pinch SNK for interactions with GS.

Interaction Plot
Effect: Glove
Dependent: Score

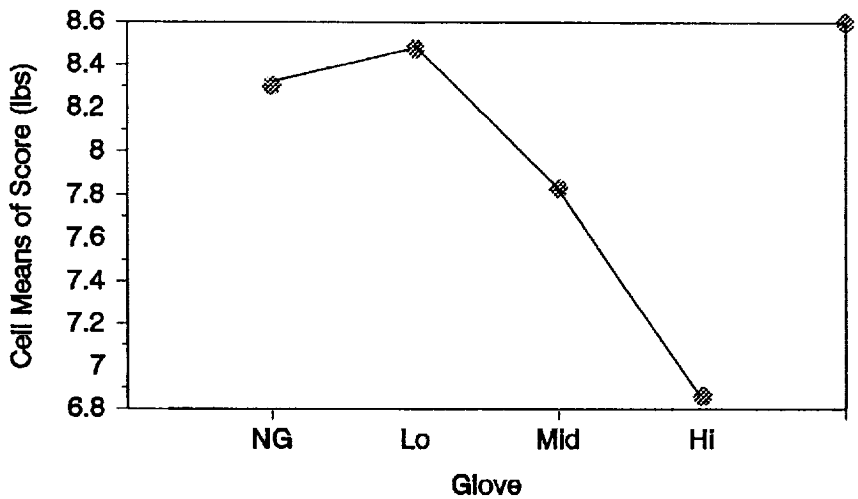


Figure 89. Graph of means versus GS for pinch.

Pinch Strength: Run * Attempt																				
	7.100	7.313	7.463	7.487	7.512	7.600	7.637	7.713	7.713	7.750	7.775	8.000	8.050	8.062	8.112	8.188	8.362	8.387	8.475	8.625
7.100	0.000	0.213	0.363	0.387	0.412	0.500	0.537	0.613	0.613	0.650	0.675	0.900	0.950	0.962	1.012	1.088	1.262	1.287	1.375	1.525.
7.313		0.000	0.150	0.174	0.199	0.287	0.324	0.400	0.400	0.437	0.462	0.687	0.737	0.749	0.799	0.875	1.049	1.074	1.162	1.312
7.463			0.000	0.024	0.049	0.137	0.174	0.250	0.250	0.287	0.312	0.537	0.587	0.599	0.649	0.725	0.899	0.924	1.012	1.162
7.487				0.000	0.025	0.113	0.150	0.226	0.226	0.263	0.288	0.513	0.563	0.575	0.625	0.701	0.875	0.900	0.988	1.138
7.512					0.000	0.088	0.125	0.201	0.201	0.238	0.263	0.488	0.538	0.550	0.600	0.676	0.850	0.875	0.963	1.113
7.600						0.000	0.037	0.113	0.113	0.150	0.175	0.400	0.450	0.462	0.512	0.588	0.762	0.787	0.875	1.025
7.637							0.000	0.076	0.076	0.113	0.138	0.363	0.413	0.425	0.475	0.551	0.725	0.750	0.838	0.988
7.713								0.000	0.000	0.037	0.062	0.287	0.337	0.349	0.399	0.475	0.649	0.674	0.762	0.912
7.713									0.000	0.037	0.062	0.287	0.337	0.349	0.399	0.475	0.649	0.674	0.762	0.912
7.750										0.000	0.025	0.250	0.300	0.312	0.362	0.438	0.612	0.637	0.725	0.875
7.775											0.000	0.225	0.275	0.287	0.337	0.413	0.587	0.612	0.700	0.850
8.000												0.000	0.050	0.062	0.112	0.188	0.362	0.387	0.475	0.625
8.050													0.000	0.012	0.062	0.138	0.312	0.337	0.425	0.575
8.062														0.000	0.050	0.126	0.300	0.325	0.413	0.563
8.112															0.000	0.076	0.250	0.275	0.363	0.513
8.188																0.000	0.174	0.199	0.287	0.437
8.362																	0.000	0.025	0.113	0.263
8.387																		0.000	0.088	0.238
8.475																			0.000	0.150
8.625																				0.000

Figure 90. Pinch test SNK calculations for Run * Attempt.

Pinch Strength: Run * Attempt (Continued)								
'alpha=.05	'df=72		q	MS	F12=MS/n	sqrt(f12)	CD	
'r=2			0.00	0.219	0.5475	0.233987	0	
'r=3			0.00	0.219	0.5475	0.233987	0	
'r=4			0.00	0.219	0.5475	0.233987	0	
'r=5			0.00	0.219	0.5475	0.233987	0	
'r=6			0.00	0.219	0.5475	0.233987	0	
'r=7			0.00	0.219	0.5475	0.233987	0	
'r=8			0.00	0.219	0.5475	0.233987	0	
'r=9			0.00	0.219	0.5475	0.233987	0	
'r=10			0.00	0.219	0.5475	0.233987	0	
'r=11			0.00	0.219	0.5475	0.233987	0	
'r=12			0.00	0.219	0.5475	0.233987	0	
'r=13			0.00	0.219	0.5475	0.233987	0	
'r=14			0.00	0.219	0.5475	0.233987	0	
'r=15			0.00	0.219	0.5475	0.233987	0	
'r=16			0.00	0.219	0.5475	0.233987	0	
'r=17			0.00	0.219	0.5475	0.233987	0	
'r=18			0.00	0.219	0.5475	0.233987	0	
'r=19			0.00	0.219	0.5475	0.233987	0	
'r=20			0.00	0.219	0.5475	0.233987	0	

Figure 90. Pinch test SNK calculations for Run * Attempt (continued).

Digit Extension

The SNK, figure 94, showed no significant pairwise interactions between GS conditions. The LSD test indicated significance in results between measurements taken in GS conditions 0 PSI and 4.3 PSI, 0 PSI and 8 PSI, and NG and 8 PSI, as shown in figure 96.

Index finger extension data shown in figure 91. Score refers to upward force exerted in pounds.

DIGIT EXTENSION RAW SUBJECT DATA						
	Subject	**Strength**	**Glove**	**Run**	**Attempt**	**Score**
• Type:	Category	Category	Category	Category	Category	Real
• Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
• Class:	Nominal	Nominal	Nominal	Nominal	Nominal	Continuous
• Format:	*	*	*	*	*	Free Format Fl...
•Dec. Places:	*	*	*	*	*	1
Mean:	*	*	*	*	*	1.4
Std. Deviation:	*	*	*	*	*	.4
Std. Error:	*	*	*	*	*	3.9E-2
Variance:	*	*	*	*	*	.1
Coeff. of Variation:	*	*	*	*	*	28.2
Minimum:	S1	Lo	NG	R1	A1	.5
Maximum:	S15	Hi	Hi	R4	A3	2.5
Range:	7.000	1.000	3.000	3.000	2.000	2.0
Count:	96	96	96	96	96	96
Missing Cells:	0	0	0	0	0	0
Sum:	*	*	*	*	*	130.4
Sum of Squares:	*	*	*	*	*	191.1
	S1	Hi	Hi	R1	A1	1.0
	S1	Hi	Hi	R1	A2	1.1
	S1	Hi	Hi	R1	A3	1.5
	S1	Hi	NG	R2	A1	1.0
	S1	Hi	NG	R2	A2	1.1
	S1	Hi	NG	R2	A3	.9
	S1	Hi	Mid	R3	A1	1.3
	S1	Hi	Mid	R3	A2	1.3
	S1	Hi	Mid	R3	A3	1.3
	S1	Hi	Lo	R4	A1	1.2
	S1	Hi	Lo	R4	A2	1.3
	S1	Hi	Lo	R4	A3	1.1
	S9	Hi	Mid	R1	A1	2.5
	S9	Hi	Mid	R1	A2	2.0
	S9	Hi	Mid	R1	A3	2.0
	S9	Hi	Hi	R2	A1	2.0
	S9	Hi	Hi	R2	A2	2.5
	S9	Hi	Hi	R2	A3	2.0
	S9	Hi	Lo	R3	A1	1.6
	S9	Hi	Lo	R3	A2	1.5
	S9	Hi	Lo	R3	A3	1.1
	S9	Hi	NG	R4	A1	1.1
	S9	Hi	NG	R4	A2	1.2
	S9	Hi	NG	R4	A3	1.2
	S11	Hi	Lo	R1	A1	1.1
	S11	Hi	Lo	R1	A2	1.3
	S11	Hi	Lo	R1	A3	1.4
	S11	Hi	Mid	R2	A1	1.0
	S11	Hi	Mid	R2	A2	1.1
	S11	Hi	Mid	R2	A3	.9
	S11	Hi	NG	R3	A1	1.2

Figure 91. Digit extension test data.

DIGIT EXTENSION
RAW SUBJECT DATA

	Subject	Strength	Glove	Run	Attempt	Score
	S11	Hi	NG	R3	A2	1.0
	S11	Hi	NG	R3	A3	1.0
	S11	Hi	Hi	R4	A1	1.4
	S11	Hi	Hi	R4	A2	1.2
	S11	Hi	Hi	R4	A3	1.2
	S13	Hi	NG	R1	A1	1.0
	S13	Hi	NG	R1	A2	1.3
	S13	Hi	NG	R1	A3	1.5
	S13	Hi	Lo	R2	A1	1.4
	S13	Hi	Lo	R2	A2	1.1
	S13	Hi	Lo	R2	A3	1.4
	S13	Hi	Hi	R3	A1	1.4
	S13	Hi	Hi	R3	A2	1.5
	S13	Hi	Hi	R3	A3	1.9
	S13	Hi	Mid	R4	A1	1.5
	S13	Hi	Mid	R4	A2	1.6
	S13	Hi	Mid	R4	A3	1.4
	S5	Lo	Lo	R1	A1	1.1
	S5	Lo	Lo	R1	A2	1.4
	S5	Lo	Lo	R1	A3	1.1
	S5	Lo	Mid	R2	A1	1.6
	S5	Lo	Mid	R2	A2	1.4
	S5	Lo	Mid	R2	A3	1.6
	S5	Lo	NG	R3	A1	1.4
	S5	Lo	NG	R3	A2	1.2
	S5	Lo	NG	R3	A3	1.2
	S5	Lo	Hi	R4	A1	1.4
	S5	Lo	Hi	R4	A2	1.4
	S5	Lo	Hi	R4	A3	1.3
	S12	Lo	NG	R1	A1	1.5
	S12	Lo	NG	R1	A2	1.5
	S12	Lo	NG	R1	A3	2.0
	S12	Lo	Lo	R2	A1	1.5
	S12	Lo	Lo	R2	A2	1.3
	S12	Lo	Lo	R2	A3	1.4
	S12	Lo	Hi	R3	A1	1.5
	S12	Lo	Hi	R3	A2	1.7
	S12	Lo	Hi	R3	A3	1.5
	S12	Lo	Mid	R4	A1	1.4
	S12	Lo	Mid	R4	A2	1.3
	S12	Lo	Mid	R4	A3	1.4
	S6	Lo	Mid	R1	A1	2.0
	S6	Lo	Mid	R1	A2	2.0
	S6	Lo	Mid	R1	A3	2.0
	S6	Lo	Hi	R2	A1	1.4
	S6	Lo	Hi	R2	A2	1.5
	S6	Lo	Hi	R2	A3	1.1
	S6	Lo	Lo	R3	A1	1.2
	S6	Lo	Lo	R3	A2	1.0
	S6	Lo	Lo	R3	A3	1.2
	S6	Lo	NG	R4	A1	1.4
	S6	Lo	NG	R4	A2	1.3
	S6	Lo	NG	R4	A3	1.6
	S15	Lo	Hi	R1	A1	2.0
	S15	Lo	Hi	R1	A2	1.0
	S15	Lo	Hi	R1	A3	2.5
	S15	Lo	NG	R2	A1	.9
	S15	Lo	NG	R2	A2	1.0
	S15	Lo	NG	R2	A3	1.0
	S15	Lo	Mid	R3	A1	.9
	S15	Lo	Mid	R3	A2	1.0
	S15	Lo	Mid	R3	A3	1.1
	S15	Lo	Lo	R4	A1	.6
	S15	Lo	Lo	R4	A2	.5
	S15	Lo	Lo	R4	A3	.5

Figure 91. Digit Extension test data (continued).

MODEL OF DIGIT EXTENSION

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.007	0.007	0.010	0.9225	Subject (Strength)
Subject (Strength)	6	3.887	0.648			
Glove	3	2.353	0.784	3.271	0.0452	Glove * Subject (Strength)
Glove * Strength	3	0.566	0.189	0.787	0.5168	Glove * Subject (Strength)
Glove * Subject (Strength)	18	4.315	0.240			
Attempt	2	0.045	0.023	0.536	0.5983	Attempt * Subject (Strength)
Attempt * Strength	2	0.089	0.044	10.055	0.3783	Attempt * Subject (Strength)
Attempt * Subject (Strength)	12	0.506	0.042			
Attempt * Glove	6	0.138	0.023	0.427	0.8563	Attempt * Glove * Subject (Strength)
Attempt * Glove * Strength	6	0.106	0.018	0.328	0.9181	Attempt * Glove * Subject (Strength)
Attempt * Glove * Subject (Strength)	36	1.943	0.054			
Residual	0	-7.5E-17	*			

Dependent: Score

Figure 92. Digit extension model.

Means Table
Effect: Glove
Dependent: Score

	Count	Mean	Std. Dev.	Std. Error
NG	24	1.229	0.263	0.054
Lo	24	1.179	0.295	0.060
Mid	24	1.483	0.418	0.085
Hi	24	1.542	0.417	0.085

Figure 93. Digit extension means table for GS interaction.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Subject Strength
Dependent: Score
Significance level: 0.05

	Versus	Diff.	Crit. diff.
Lo	NG	0.050	0.297
	Mid	0.304	0.361
	Hi	0.362	0.400
NG	Mid	0.254	0.297
	Hi	0.312	0.361
Mid	Hi	0.058	0.297

None were significantly different at this level.

Figure 94. Digit extension SNK for GS.

Interaction Plot
Effect: Glove
Dependent: Score

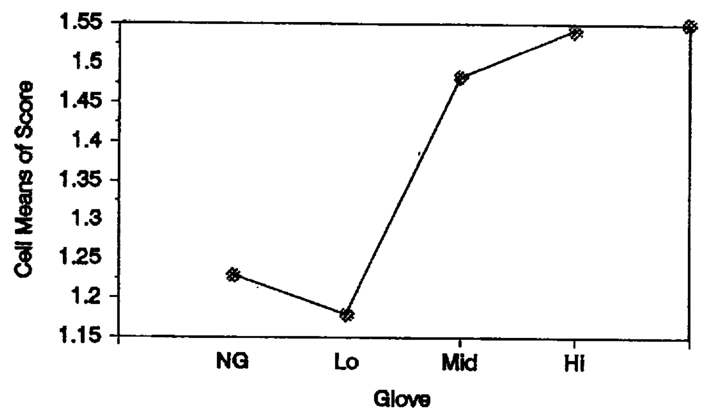


Figure 95. Graph of digit extension means versus GS.

Fisher's Protected LSD
Effect: Glove
Error term: Type I sum of squares for Subject Strength
Dependent: Score
Significance level: 0.05

	Versus	Diff.	Crit. diff.	P-Value	
Lo	NG	0.050	0.297	0.7276	
	Mid	0.304	0.297	0.0452	S
	Hi	0.362	0.297	0.0195	S
NG	Mid	0.254	0.297	0.0889	
	Hi	0.312	0.297	0.0402	S
Mid	Hi	0.058	0.297	0.6847	

S = Significantly different at this level.

Figure 96. Digit extension LSD for GS.

Fingertip Tactility

In figure 97, score refers to number of centimeters before separation was noted. Gradations below 1/2 cm were not used due to the finger width on the diverging surfaces.

FINGERTIP TACTILITY RAW SUBJECT DATA						
	Subject	**Strength**	**Glove**	**Run**	**Gap**	**Score**
• **Type:**	Category	Category	Category	Category	Category	Real
• **Source:**	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
• **Class:**	Nominal	Nominal	Nominal	Nominal	Nominal	Continuous
• **Format:**	*	*	*	*	*	Free Format Fl...
• **Dec. Places:**	*	*	*	*	*	1
Mean:	*	*	*	*	*	4.0
Std. Deviation:	*	*	*	*	*	3.0
Std. Error:	*	*	*	*	*	.3
Variance:	*	*	*	*	*	8.8
Coeff. of Variation:	*	*	*	*	*	74.0
Minimum:	S1	Lo	NG	R1	G0.5	0.0
Maximum:	S15	Hi	Hi	R4	G1.5	16.0
Range:	7.000	1.000	3.000	3.000	2.000	16.0
Count:	96	96	96	96	96	96
Missing Cells:	0	0	0	0	0	0
Sum:	*	*	*	*	*	384.0
Sum of Squares:	*	*	*	*	*	2367.5
	S1	Hi	Hi	R1	G1.0	3.0
	S1	Hi	Hi	R1	G1.5	1.0
	S1	Hi	Hi	R1	G0.5	4.0
	S1	Hi	NG	R2	G1.0	3.0
	S1	Hi	NG	R2	G1.5	1.5
	S1	Hi	NG	R2	G0.5	3.0
	S1	Hi	Mid	R3	G1.5	1.5
	S1	Hi	Mid	R3	G0.5	2.5
	S1	Hi	Mid	R3	G1.0	3.0
	S1	Hi	Lo	R4	G0.5	3.5
	S1	Hi	Lo	R4	G1.0	1.0
	S1	Hi	Lo	R4	G1.5	1.0
	S9	Hi	Mid	R1	G1.0	6.0
	S9	Hi	Mid	R1	G1.5	3.0
	S9	Hi	Mid	R1	G0.5	6.0
	S9	Hi	Hi	R2	G1.0	3.0
	S9	Hi	Hi	R2	G1.5	3.5
	S9	Hi	Hi	R2	G0.5	8.0
	S9	Hi	Lo	R3	G1.5	4.0
	S9	Hi	Lo	R3	G0.5	7.0
	S9	Hi	Lo	R3	G1.0	4.5
	S9	Hi	NG	R4	G0.5	6.0
	S9	Hi	NG	R4	G1.0	2.5
	S9	Hi	NG	R4	G1.5	2.0
	S11	Hi	Lo	R1	G1.5	2.0
	S11	Hi	Lo	R1	G0.5	1.5
	S11	Hi	Lo	R1	G1.0	1.0
	S11	Hi	Mid	R2	G0.5	3.5
	S11	Hi	Mid	R2	G1.0	2.5
	S11	Hi	Mid	R2	G1.5	1.0
	S11	Hi	NG	R3	G0.5	1.0
	S11	Hi	NG	R3	G1.0	.5
	S11	Hi	NG	R3	G1.5	0.0
	S11	Hi	Hi	R4	G0.5	2.0
	S11	Hi	Hi	R4	G1.0	1.0
	S11	Hi	Hi	R4	G1.5	1.0

Figure 97. Fingertip tactility test data.

FINGERTIP TACTILITY RAW SUBJECT DATA					
Subject	Strength	Glove	Run	Gap	Score
S13	Hi	NG	R1	G0.5	6.0
S13	Hi	NG	R1	G1.0	5.0
S13	Hi	NG	R1	G1.5	4.0
S13	Hi	Lo	R2	G0.5	11.0
S13	Hi	Lo	R2	G1.0	5.0
S13	Hi	Lo	R2	G1.5	4.0
S13	Hi	Hi	R3	G1.5	2.0
S13	Hi	Hi	R3	G0.5	3.0
S13	Hi	Hi	R3	G1.0	2.5
S13	Hi	Mid	R4	G0.5	3.0
S13	Hi	Mid	R4	G1.0	3.0
S13	Hi	Mid	R4	G1.5	1.5
S5	Lo	Lo	R1	G1.5	5.0
S5	Lo	Lo	R1	G1.0	16.0
S5	Lo	Lo	R1	G1.0	7.0
S5	Lo	Mid	R2	G1.0	6.5
S5	Lo	Mid	R2	G1.5	3.5
S5	Lo	Mid	R2	G0.5	6.0
S5	Lo	NG	R3	G1.0	3.5
S5	Lo	NG	R3	G1.5	2.0
S5	Lo	NG	R3	G0.5	2.0
S5	Lo	Hi	R4	G1.0	5.0
S5	Lo	Hi	R4	G1.5	4.5
S5	Lo	Hi	R4	G0.5	5.0
S12	Lo	NG	R1	G1.0	4.5
S12	Lo	NG	R1	G1.5	1.5
S12	Lo	NG	R1	G0.5	1.0
S12	Lo	Lo	R2	G1.0	1.0
S12	Lo	Lo	R2	G1.5	.5
S12	Lo	Lo	R2	G0.5	.5
S12	Lo	Hi	R3	G1.5	1.0
S12	Lo	Hi	R3	G0.5	1.0
S12	Lo	Hi	R3	G1.0	.5
S12	Lo	Mid	R4	G1.0	.5
S12	Lo	Mid	R4	G1.5	1.0
S12	Lo	Mid	R4	G0.5	1.0
S6	Lo	Mid	R1	G1.5	3.0
S6	Lo	Mid	R1	G0.5	9.0
S6	Lo	Mid	R1	G1.0	5.0
S6	Lo	Hi	R2	G1.0	3.5
S6	Lo	Hi	R2	G1.5	2.5
S6	Lo	Hi	R2	G0.5	8.0
S6	Lo	Lo	R3	G1.5	5.0
S6	Lo	Lo	R3	G0.5	14.0
S6	Lo	Lo	R3	G1.0	8.0
S6	Lo	NG	R4	G1.0	5.0
S6	Lo	NG	R4	G1.5	5.0
S6	Lo	NG	R4	G0.5	10.5
S15	Lo	Hi	R1	G1.0	6.0
S15	Lo	Hi	R1	G1.5	4.5
S15	Lo	Hi	R1	G0.5	9.0
S15	Lo	NG	R2	G1.5	3.5
S15	Lo	NG	R2	G0.5	7.5
S15	Lo	NG	R2	G1.0	6.5
S15	Lo	Mid	R3	G1.0	7.0
S15	Lo	Mid	R3	G1.5	5.0
S15	Lo	Mid	R3	G0.5	8.0
S15	Lo	Lo	R4	G1.5	5.0
S15	Lo	Lo	R4	G0.5	7.0
S15	Lo	Lo	R4	G1.0	6.0

Figure 97. Fingertip tactility test data (continued).

TACTILITY MODEL

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	71.760	71.760	1.397	0.2820	Subject (Strength)
Subject (Strength)	6	308.281	51.380			
Glove	3	32.562	11.521	1.718	0.1990	Glove * Subject (Strength)
Glove * Strength	3	4.385	1.462	0.218	0.8826	Glove * Subject (Strength)
Glove * Subject (Strength)	18	120.677	6.704			
Gap	2	131.078	65.539	12.552	0.0011	Gap * Subject (Strength)
Gap * Strength	2	3.599	1.799	0.345	0.7153	Gap * Subject (Strength)
Gap * Subject (Strength)	12	62.656	5.221			
Gap * Glove	6	21.859	3.643	1.950	0.0991	Gap * Glove * Subject (Strength)
Gap * Glove * Strength	6	5.380	.897	0.480	0.8188	Gap * Glove * Subject (Strength)
Gap * Glove * Subject (Strength)	36	67.260	1.868			
Residual	0	-9.890E-17	*			

Dependent: Score

Figure 98. Tactility model.

Means Table
Effect: Gap
Dependent: Score

	Count	Mean	Std. Dev.	Std. Error
G0.5	32	5.516	3.915	.692
G1.0	32	3.812	2.184	.386
G1.5	32	2.672	1.579	.279

Figure 99. Tactility means table for gap size.

Student-Newman-Keuls
Effect: Gap
Error term: Type I sum of squares for Subject Strength
Dependent: Score
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
G1.5	G1.0	1.141	1.244	
	G0.05	2.844	1.523	S
G1.0	G0.5	1.141	1.244	S

S = Significantly different at this level.

Figure 100. Tactility SNK for gap size.

TACTILITY MODEL

Interaction Plot
Effect: Gap
Dependent: Score

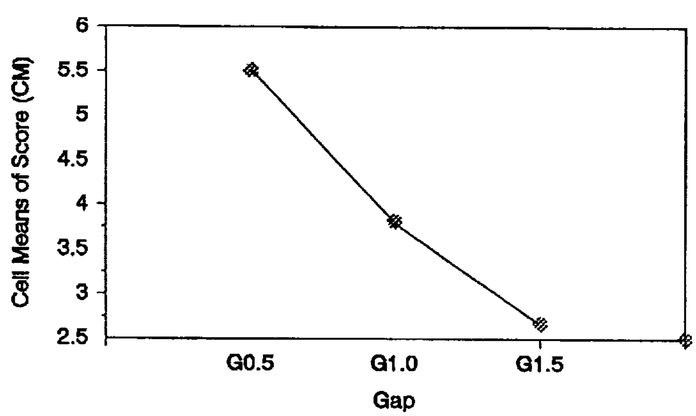


Figure 101. Tactility graph of mean versus gap size.

Dexterity

The number of bolts inserted was taken at 15, 30, and 60 s; these are the Score_15, Score_30, and Score_60 columns respectively. Drops were counted as errors in the data in figure 102.

DEXTERITY RAW SUBJECT DATA								
	Subject	**Strength**	**Glove**	**Run**	**Score_15**	**Score_30**	**Score_60**	**Errors**
•Type:	Category	Category	Category	Category	Integer	Integer	Integer	Integer
•Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
•Class:	Nominal	Nominal	Nominal	Nominal	Continuous	Continuous	Continuous	Continuous
•Format:	*	*	*	*	*	*	*	*
•Dec. Places:	*	*	*	*	*	*	*	*
Mean:	*	*	*	*	.719	1.406	2.906	1.438
Std. Deviation:	*	*	*	*	1.143	1.982	3.830	1.162
Std. Error:	*	*	*	*	.202	.350	.677	.205
Variance:	*	*	*	*	1.305	3.926	14.668	1.351
Coeff. of Variation:	*	*	*	*	158.965	140.908	131.782	80.852
Minimum:	S1	Lo	NG	R1	0	0	0	0
Maximum:	S15	Hi	Hi	R4	4	7	13	4
Range:	7.000	1.00	3.000	3.000	4.000	7.000	13.000	4.000
Count:	32	32	32	32	32	32	32	32
Missing Cells:	-	0	0	0	0	0	0	0
Sum:	*	*	*	*	23.000	45.000	93.000	46.000
Sum of Squares:	*	*	*	*	57.000	185.000	725.000	108.000
	S1	Hi	Hi	R1	0	0	0	0
	S1	Hi	NG	R2	3	6	10	0
	S1	Hi	Mid	R3	0	0	0	2
	S1	Hi	Lo	R4	3	4	6	1
	S9	Hi	Mid	R1	0	0	0	0
	S9	Hi	Hi	R2	0	0	0	1
	S9	Hi	Lo	R3	1	3	4	2
	S9	Hi	NG	R4	2	3	8	0
	S11	Hi	Lo	R1	0	2	5	3
	S11	Hi	Mid	R2	0	0	0	2
	S11	Hi	NG	R3	4	7	13	1
	S11	Hi	Hi	R4	0	0	0	4
	S13	Hi	NG	R1	1	4	11	0
	S13	Hi	Lo	R2	1	1	2	1
	S13	Hi	Hi	R3	0	0	0	1
	S13	Hi	Mid	R4	0	0	0	3
	S5	Lo	Lo	R1	0	0	1	2
	S5	Lo	Mid	R2	0	0	0	1
	S5	Lo	NG	R3	2	2	5	1
	S5	Lo	Hi	R4	0	0	0	1
	S12	Lo	NG	R1	3	5	9	0
	S12	Lo	Lo	R2	1	1	3	2
	S12	Lo	Hi	R3	0	0	0	3
	S12	Lo	Mid	R4	0	0	0	1
	S6	Lo	Mid	R1	0	0	0	1
	S6	Lo	Hi	R2	0	0	0	1
	S6	Lo	Lo	R3	0	1	3	3
	S6	Lo	NG	R4	1	3	6	2
	S15	Lo	Hi	R1	0	0	0	2
	S15	Lo	NG	R2	1	2	5	0
	S15	Lo	Mid	R3	0	0	0	4
	S15	Lo	Lo	R4	0	1	2	1

Figure 102. Dexterity test data.

MODEL OF DEXTERITY PERFORMANCE OVER RUNS

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	1.531	1.531	2.492	0.1655	Subject (Strength)
Subject (Strength)	6	3.688	0.615			
Run	3	0.594	0.198	0.111	0.9525	Run * Subject (Strength)
Run * Strength	3	2.594	0.865	0.485	0.6967	Run * Subject (Strength)
Run * Subject (Strength)	18	32.062	1.781			
Residual	0	-2.168E-19	*			

Dependent: Score_15

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	7.031	7.031	6.553	0.0429	Subject (Strength)
Subject (Strength)	6	6.438	1.073			
Run	3	.594	0.198	0.034	0.9914	Run * Subject (Strength)
Run * Strength	3	2.344	0.781	0.134	0.9388	Run * Subject (Strength)
Run * Subject (Strength)	18	105.312	5.851			
Residual	0	3.551E-18	*			

Dependent: Score_30

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	19.531	19.531	10.714	0.0170	Subject (Strength)
Subject (Strength)	6	10.938	1.823			
Run	3	2.844	0.948	0.041	0.9887	Run * Subject (Strength)
Run * Strength	3	1.594	0.531	0.023	0.9952	Run * Subject (Strength)
Run * Subject (Strength)	18	419.813	23.323			
Residual	0	-1.420E-17	*			

Dependent: Score_60

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	.500	0.500	0.338	0.5821	Subject (Strength)
Subject (Strength)	6	8.875	1.479			
Run	3	7.125	2.375	2.024	0.1466	Run * Subject (Strength)
Run * Strength	3	4.250	1.417	1.207	0.3356	Run * Subject (Strength)
Run * Subject (Strength)	18	21.125	1.174			
Residual	0	4.608E-18	*			

Dependent: Errors

Figure 103. Dexterity model of performance interactions with Runs.

DEXTERITY MODEL

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	1.531	1.531	2.492	0.1655	Subject (Strength)
Subject (Strength)	6	3.688	0.651			
Glove	3	24.094	8.031	15.118	0.0001	Glove * Subject (Strength)
Glove * Strength	3	1.564	0.531	1.000	0.4155	Glove * Subject (Strength)
Glove * Subject (Strength)	18	9.562	0.531			
Residual	0	1.274E-18	*			

Dependent: Score_15

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	7.031	7.031	6.553	0.0429	Subject (Strength)
Subject (Strength)	6	6.438	1.073			
Glove	3	85.844	28.615	33.637	0.0001	Glove * Subject (Strength)
Glove * Strength	3	7.094	2.365	2.780	0.0709	Glove * Subject (Strength)
Glove * Subject (Strength)	18	15.312	0.851			
Residual	0	1.355E-18	*			

Dependent: Score_30

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	19.531	19.531	10.714	0.0170	Subject (Strength)
Subject (Strength)	6	10.938	1.823			
Glove	3	375.344	125.115	92.630	0.0001	Glove * Subject (Strength)
Glove * Strength	3	24.594	8.198	6.069	0.0049	Glove * Subject (Strength)
Glove * Subject (Strength)	18	24.312	1.351			
Residual	0	7.210E-18	*			

Dependent: Score_60

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.500	0.500	0.338	0.5821	Subject (Strength)
Subject (Strength)	6	8.875	1.479			
Glove	3	9.625	3.208	2.552	0.0878	Glove * Subject (Strength)
Glove * Strength	3	0.250	0.083	0.066	0.9771	Glove * Subject (Strength)
Glove * Subject (Strength)	18	22.625	1.257			
Residual	0	3.469E-18	*			

Dependent: Errors

Figure 104. Dexterity model of performance interactions with GS.

No significant interaction of performance with runs is shown in figure 103, however interactions with GS and GS * Strength appear in figure 104.

Means Table
Effect: Glove
Dependent: Score_15

	Count	Mean	Std. Dev.	Std. Error
NG	8	2.125	1.126	0.398
Lo	8	0.750	1.035	0.366
Mid	8	0.000	0.000	0.000
Hi	8	0.000	0.000	0.000

Means Table
Effect: Glove
Dependent: Score_30

	Count	Mean	Std. Dev.	Std. Error
NG	8	4.000	1.852	0.655
Lo	8	1.625	1.302	0.460
Mid	8	0.000	0.000	0.000
Hi	8	0.000	0.000	0.000

Means Table
Effect: Glove
Dependent: Score_60

	Count	Mean	Std. Dev.	Std. Error
NG	8	8.375	2.925	1.034
Lo	8	3.250	1.669	0.590
Mid	8	0.000	0.000	0.000
Hi	8	0.000	0.000	0.000

Figure 105. Dexterity means table for GS.

Means Table
Effect: Strength
Dependent: Score_30

	Count	Mean	Std. Dev.	Std. Error
Lo	16	0.938	1.436	0.359
Hi	16	1.875	2.363	0.591

Means Table
Effect: Strength
Dependent: Score_60

	Count	Mean	Std. Dev.	Std. Error
Lo	16	2.125	2.802	0.700
Hi	16	3.688	4.600	1.150

Figure 106. Dexterity means tables for strength.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_15
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Hi	Mid	0.000	0.765	
	Lo	0.750	0.930	
	NG	2.125	1.031	S
Mid	Lo	0.750	0.765	
	NG	2.125	0.930	S
Lo	NG	1.375	0.765	S

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_30
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Hi	Mid	0.000	0.968	
	Lo	1.625	1.177	S
	NG	4.000	1.304	S
Mid	Lo	1.625	0.968	S
	NG	4.000	1.177	S
Lo	NG	2.375	0.968	S

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_60
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Hi	Mid	0.000	1.220	
	Lo	3.250	1.483	S
	NG	8.375	1.644	S
Mid	Lo	3.250	1.220	S
	NG	8.375	1.483	S
Lo	NG	5.125	1.220	S

S = Significantly different at this level.

Figure 107. Dexterity SNK for GS.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_30
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Lo	Hi	.938	0.896	S

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_60
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Lo	Hi	1.562	1.168	S

S = Significantly different at this level.

Figure 108. Dexterity SNK for Strength.

Means Table
Effect: Glove * Strength
Dependent: Score_30

	Count	Mean	Std. Dev.	Std. Error
NG, Lo	4	6.250	1.893	0.946
NG, Hi	4	10.500	2.082	1.041
Lo, Lo	4	2.250	0.957	0.479
Lo, Hi	4	4.250	1.708	0.854
Mid, Lo	4	0.000	0.000	0.000
Mid, Hi	4	0.000	0.000	0.000
Hi, Lo	4	0.000	0.000	0.000
Hi, Hi	4	0.000	0.000	0.000

Figure 109. Dexterity means table for Glove * Strength at 30 s.

Interaction Plot
Effect: Glove * Strength
Dependent: Score_60

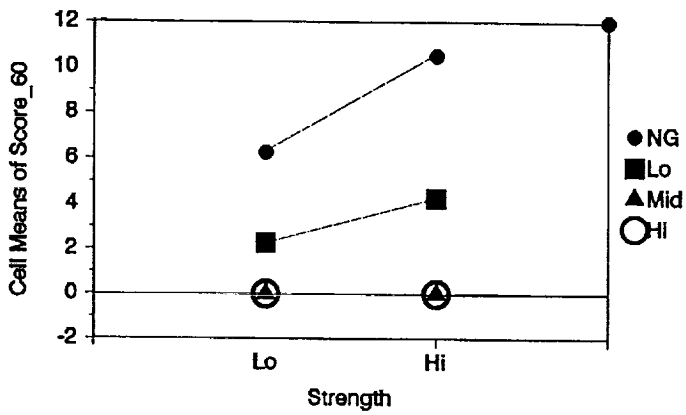


Figure 110. Graph of Dexterity 60-s means versus strength for GS.

Interaction Plot
Effect: Glove
Dependent: Score_15

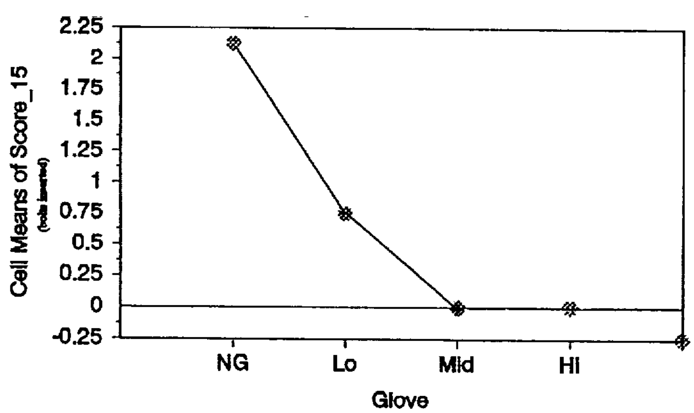
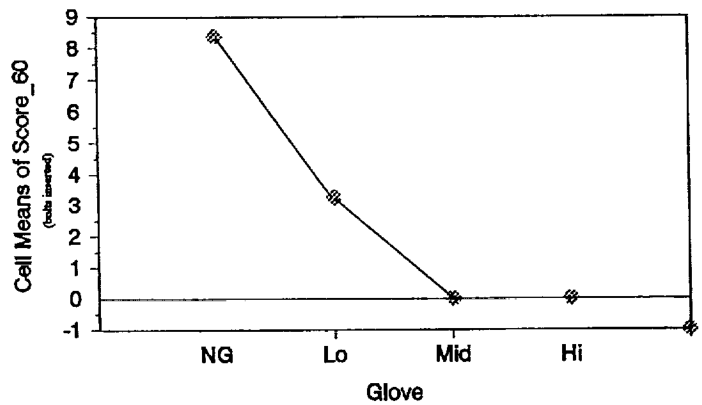


Figure 111. Graphs of dexterity means versus GS.

Interaction Plot
Effect: Glove
Dependent: Score_30



Interaction Plot
Effect: Glove
Dependent: Score_60

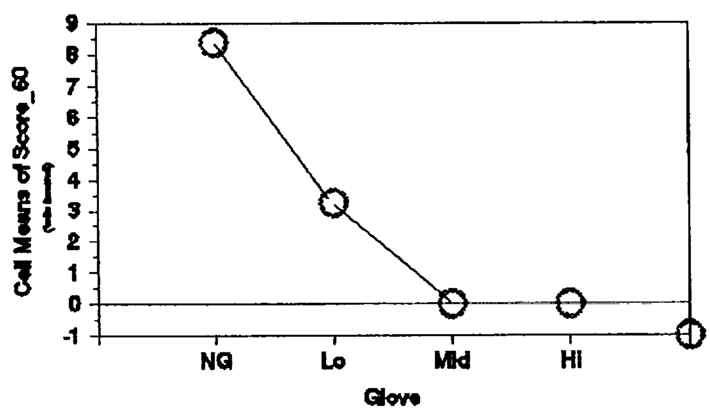


Figure 111. Graphs of dexterity means versus GS (continued).

Dexterity: Glove * Strength at 60 s

	0.000	0.000	0.000	0.000	2.250	4.250	6.250	10.500
0.000	0.000	0.000	0.000	0.000	2.250	4.250	6.250	10.500
0.000		0.000	0.000	0.000	2.250	4.250	6.250	10.500
0.000			0.000	0.000	2.250	4.250	6.250	10.500
0.000				0.000	2.250	4.250	6.250	10.500
2.250					0.000	2.000	4.000	8.250
4.250						0.000	2.000	6.250
6.250							0.000	4.250
10.500								0.000
alpha=0.05	'df=18		q	MS	F12=MS/n	sqrt(f12)	CD	
'r=2	2.97		2.97	1.351	0.33775	0.581163	1.726053	
'r=3	3.61		3.61	1.351	0.33775	0.581163	2.097997	
'r=4	4.00		4.00	1.351	0.33775	0.581163	2.324651	
'r=5	4.28		4.28	1.351	0.33775	0.581163	2.487376	
'r=6	4.49		4.49	1.351	0.33775	0.581163	2.60942	
'r=7	4.67		4.67	1.351	0.33775	0.581163	2.714029	
'r=8	4.82		4.82	1.351	0.33775	0.581163	2.801204	

Figure 112. Dexterity SNK calculated for Glove * Strength at 60 s.

Integrated Task: EVA Tether

The number of times the tether hook had been released and closed was taken at 15, 30, and 60 s. Data is shown in figure 113.

INTEGRATED TASK: EVA TETHER TEST DATA RAW SUBJECT DATA									
	Subject	**Strength**	**Glove**	**Run**	**Score_15**	**Score_30**	**Score_60**	**Drops**	**Recovery**
•Type:	Category	Category	Category	Category	Integer	Integer	Integer	Integer	Integer
•Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
•Class:	Nominal	Nominal	Nominal	Nominal	Continuous	Continuous	Continuous	Continuous	Continuous
•Format:	*	*	*	*	Free Format Fi	Free Format FI	Free Format FI	*	*
•Dec. Places:	*	*	*	*	1	1	1	*	*
Mean:	*	*	*	*	4.9	10.6	21.0	0.469	0.219
Std. Deviation:	*	*	*	*	5.7	11.6	22.8	0.761	0.608
Std. Error:	*	*	*	*	1.0	2.1	4.0	0.135	0.108
Variance:	*	*	*	*	32.0	134.5	519.8	0.580	0.370
Coeff. of Variation:	*	*	*	*	114.6	109.5	108.7	162.419	2780.054
Minimum:	S1	Lo	NG	R1	0.0	0.0	0.0	0	0
Maximum:	S15	Hi	Hi	R4	17.0	34.0	68.0	3	3
Range:	7.000	1.00	3.000	3.000	32	34.0	68.0	3.000	3.000
Count:	32	32	32	32	32	32	32.0	32	32
Missing Cells:	-	0	0	0	0	0	0	0	0
Sum:	*	*	*	*	158.0	339.0	671.0	15.000	7.000
Sum of Squares:	*	*	*	*	1772.0	7761.0	30183.0	25.000	13.000
	S1	Hi	Hi	R1	0.0	1.0	1.0	1	0
	S1	Hi	NG	R2	16.0	34.0	56.0	0	0
	S1	Hi	Mid	R3	2.0	6.0	8.0	1	1
	S1	Hi	Lo	R4	17.0	26.0	46.0	0	0
	S9	Hi	Mid	R1	3.0	5.0	9.0	0	0
	S9	Hi	Hi	R2	0.0	0.0	0.0	0	0
	S9	Hi	Lo	R3	6.0	13.0	21.0	0	0
	S9	Hi	NG	R4	9.0	26.0	60.0	0	0
	S11	Hi	Lo	R1	10.0	20.0	46.0	0	0
	S11	Hi	Mid	R2	1.0	2.0	2.0	1	1
	S11	Hi	NG	R3	16.0	34.0	68.0	0	0
	S11	Hi	Hi	R4	0.0	0.0	0.0	2	1
	S13	Hi	NG	R1	15.0	32.0	57.0	0	0
	S13	Hi	Lo	R2	13.0	29.0	50.0	0	0
	S13	Hi	Hi	R3	1.0	1.0	1.0	1	0
	S13	Hi	Mid	R4	3.0	4.0	8.0	0	0
	S5	Lo	Lo	R1	2.0	7.0	17.0	0	0
	S5	Lo	Mid	R2	0.0	0.0	1.0	3	3
	S5	Lo	NG	R3	9.0	19.0	38.0	0	0
	S5	Lo	Hi	R4	0.0	0.0	0.0	1	0
	S12	Lo	NG	R1	10.0	19.0	46.0	0	0
	S12	Lo	Lo	R2	6.0	14.0	28.0	0	0
	S12	Lo	Hi	R3	0.0	0.0	0.0	1	0
	S12	Lo	Mid	R4	1.0	2.0	2.0	0	0
	S6	Lo	Mid	R1	0.0	0.0	0.0	1	0
	S6	Lo	Hi	R2	0.0	0.0	0.0	0	0
	S6	Lo	Lo	R3	2.0	5.0	12.0	0	0
	S6	Lo	NG	R4	9.0	20.0	48.0	0	0
	S15	Lo	Hi	R1	0.0	0.0	0.0	1	0
	S15	Lo	NG	R2	5.0	12.0	30.0	0	0
	S15	Lo	Mid	R3	0.0	2.0	2.0	2	1
	S15	Lo	Lo	R4	2.0	6.0	14.0	0	0

Figure 113. EVA tether test data.

In figure 113, Score_15, Score_30 and Score_60 refer to the number of cycles completed at 15, 30 and 60 s, respectively. Drops are the number of times during the task that the subject dropped the EVA hook. Recovery indicates the number of times a dropped tool was recovered. Zero drops and recoveries means the subject never lost grip of the hook; a greater number of drops than recoveries indicated that the subject spent the remaining test time after dropping the hook, attempting to recover it.

EVA TETHER TEST MODEL:
Tether performance interactions with Runs

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	136.125	136.125	150.055	0.0082	Subject (Strength)
Subject (Strength)	6	54.250	9.042			
Run	3	2.125	0.708	0.016	0.016	Run * Subject (Strength)
Run * Strength	3	1.6250	.542	0.012	0.012	Run * Subject (Strength)
Run * Subject (Strength)	18	797.750	44.319			
Residual	0	-5.516E-17	*			

Dependent: Score_15

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	504.031	504.031	26.198	0.0022	Subject (Strength)
Subject (Strength)	6	115.438	19.240			
Run	3	7.844	2.615	0.013	0.9978	Run * Subject (Strength)
Run * Strength	3	10.094	3.365	0.017	0.9968	Run * Subject (Strength)
Run * Subject (Strength)	18	3532.313	196.240			
Residual	0	-1.955E-16	*			

Dependent: Score_30

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	1188.281	1188.281	30.740	0.0015	Subject (Strength)
Subject (Strength)	6	231.938	38.656			
Run	3	61.094	20.365	0.025	0.9944	Run * Subject (Strength)
Run * Strength	3	1.344	0.448	0.001	1.0000	Run * Subject (Strength)
Run * Subject (Strength)	18	14630.313	812.795			
Residual	0	-7.928E-16	*			

Dependent: Score_60

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.281	0.281	0.574	0.4772	Subject (Strength)
Subject (Strength)	6	2.938	0.490			
Run	3	0.344	0.115	0.149	0.9288	Run * Subject (Strength)
Run * Strength	3	0.594	0.198	0.258	0.8547	Run * Subject (Strength)
Run * Subject (Strength)	18	13.812	0.767			
Residual	0	-1.247E-18	*			

Dependent: Drops

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.031	0.031	0.086	0.7796	Subject (Strength)
Subject (Strength)	6	2.188	0.365			
Run	3	1.094	0.365	0.868	0.4759	Run * Subject (Strength)
Run * Strength	3	0.594	0.198	0.471	0.7062	Run * Subject (Strength)
Run * Subject (Strength)	18	7.562	0.420			
Residual	0	1.897E-19	*			

Dependent: Recovery

Figure 114. Tether test interactions with runs.

Figure 114 shows the EVA tether hook test scores interaction with runs for 15, 30, and 60 s, along with drops and recoveries. P-values less than 0.05 indicate significant interactions.

EVA TETHER TEST MODEL:

Tether performance interactions with GS condition

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	136.125	136.125	150.055	0.0082	Subject (Strength)
Subject (Strength)	6	54.250	9.042			
Glove	3	643.125	214.375	50.941	0.0001	Glove * Subject (Strength)
Glove * Strength	3	82.625	27.542	6.545	0.0035	Glove * Subject (Strength)
Glove * Subject (Strength)	18	75.750	4.208			
Residual	0	-5.638E-18	*			

Dependent: Score_15

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	504.031	504.031	26.198	0.0022	Subject (Strength)
Subject (Strength)	6	115.438	19.240			
Glove	3	3066.344	1022.115	100.915	0.0001	Glove * Subject (Strength)
Glove * Strength	3	301.594	100.531	9.926	0.0004	Glove * Subject (Strength)
Glove * Subject (Strength)	18	182.313	10.128			
Residual	0	-2.423E-17	*			

Dependent: Score_30

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	1188.281	1188.281	30.740	0.0015	Subject (Strength)
Subject (Strength)	6	231.938	38.656			
Glove	3	13204.094	4401.365	101.856	0.0001	Glove * Subject (Strength)
Glove * Strength	3	710.844	236.948	5.483	0.0074	Glove * Subject (Strength)
Glove * Subject (Strength)	18	777.812	43.212			
Residual	0	-3.673E-16	*			

Dependent: Score_60

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	.281	0.281	0.574	0.4772	Subject (Strength)
Subject (Strength)	6	2.938	0.490			
Glove	3	7.094	2.365	7.323	0.0021	Glove * Subject (Strength)
Glove * Strength	3	1.844	0.615	1.903	0.1653	Glove * Subject (Strength)
Glove * Subject (Strength)	18	5.812	0.323			
Residual	0	-2.168E-19	*			

Dependent: Drops

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.031	0.031	0.086	0.7796	Subject (Strength)
Subject (Strength)	6	2.188	0.365			
Glove	3	3.094	1.031	3.337	0.0427	Glove * Subject (Strength)
Glove * Strength	3	0.594	0.198	0.640	0.5988	Glove * Subject (Strength)
Glove * Subject (Strength)	18	5.562	0.309			
Residual	0	1.355E-19	*			

Dependent: Recovery

Figure 115. EVA tether test interactions with GS condition.

Figure 115 shows the tether test interactions with GS conditions for 15, 30 and 60 s, as well as subject drops and recoveries of the EVA hook during the test. Means tables and SNK post-hoc tables indicating significant pairwise interactions are generated for interactions in figure 115 with P-values less than 00.05.

Means Table
Effect: Strength
Dependent: Score_15

	Count	Mean	Std. Dev.	Std. Error
Lo	16	2.875	3.686	0.921
Hi	16	7.000	6.593	1.648

Means Table
Effect: Strength
Dependent: Score_30

	Count	Mean	Std. Dev.	Std. Error
Lo	16	6.625	7.650	1.912
Hi	16	14.562	13.633	3.408

Means Table
Effect: Strength
Dependent: Score_60

	Count	Mean	Std. Dev.	Std. Error
Lo	16	14.875	17.599	4.400
Hi	16	27.062	26.178	6.544

Means Table
Effect: Strength
Dependent: Drops

	Count	Mean	Std. Dev.	Std. Error
Lo	16	0.562	0.892	0.223
Hi	16	0.375	0.619	0.155

Means Table
Effect: Strength
Dependent: Recovery

	Count	Mean	Std. Dev.	Std. Error
Lo	16	0.250	0.775	0.194
Hi	16	0.188	0.403	0.101

Figure 116. EVA tether means tables for strength interactions.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Score_15
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Lo	Hi	4.125	2.601	S

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Score_30
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Lo	Hi	7.938	3.794	S

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Score_60
Significance level: 0.05

	Versus	Diff.	Crit. diff.
Lo	Hi	12.188	5.378

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Drops
Significance level: 0.05

	Versus	Diff.	Crit. diff.
Hi	Lo	0.188	0.605

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Recovery
Significance level: 0.05

	Versus	Diff.	Crit. diff.
Hi	Lo	0.062	0.522

S = Significantly different at this level.

Figure 117. EVA tether SNK tables for strength interactions.

Figures 116 and 117 are the means and SNK tables for strength interactions in EVA tether performance. An "S" next to a row in the SNK table indicates a statistically significant pairwise interaction.

Means Table
Effect: Glove
Dependent: Score_15

	Count	Mean	Std. Dev.	Std. Error
NG	8	11.125	40.051	1.432
Lo	8	7.250	5.625	1.989
Mid	8	1.250	1.282	0.453
Hi	8	0.125	0.354	0.125

Means Table
Effect: Glove
Dependent: Score_30

	Count	Mean	Std. Dev.	Std. Error
NG	8	24.500	8.246	2.915
Lo	8	15.000	9.196	3.251
Mid	8	2.625	2.200	0.778
Hi	8	0.250	0.463	0.164

Means Table
Effect: Glove
Dependent: Score_60

	Count	Mean	Std. Dev.	Std. Error
NG	8	50.375	12.374	4.375
Lo	8	29.250	15.773	5.577
Mid	8	4.000	3.665	1.296
Hi	8	0.250	0.463	0.164

Means Table
Effect: Glove
Dependent: Drops

	Count	Mean	Std. Dev.	Std. Error
NG	8	0.000	0.000	0.000
Lo	8	0.000	0.000	0.000
Mid	8	1.000	1.069	0.378
Hi	8	0.875	0.641	0.227

Means Table
Effect: Glove
Dependent: Recovery

	Count	Mean	Std. Dev.	Std. Error
NG	8	0.000	0.000	0.000
Lo	8	0.000	0.000	0.000
Mid	8	0.750	1.035	0.366
Hi	8	0.125	0.354	0.125

Figure 118. EVA tether means tables for GS interactions.

Figure 118 is the set of means tables for EVA tether test performance interactions with GS condition. These tables are presented since Glove interactions, as shown in figure 115, had P-values less than 0.05. These means are used to calculate the SNK values presented in figure 119. In cases where significant pairwise differences are indicated graphs of the cell means have been made. These graphs are presented in figure 120.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_15
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Hi	Mid	1.125	2.154	
	Lo	7.125	2.618	S
	NG	11.000	2.901	S
Mid	Lo	6.000	2.154	S
	NG	9.875	2.618	S
Lo	NG	3.875	2.154	S

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_30
Significance level: 0.05

	Versus	Diff.	Crit. diff.
Hi	Mid	2.375	3.342
	Lo	14.750	4.062
	NG	24.250	4.501
Mid	Lo	12.375	3.342
	NG	21.875	4.062
Lo	NG	9.500	3.342

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_60
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Hi	Mid	3.750	6.903	
	Lo	29.000	8.390	S
	NG	50.125	9.296	S
Mid	Lo	25.250	6.903	S
	NG	46.375	8.390	S
Lo	NG	21.125	6.903	S

S = Significantly different at this level.

Figure 119. SNK tables for EVA tether performance interactions with GS.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Drops
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
NG	Lo	0.000	0.597	
	Hi	0.875	0.725	S
	Mid	1.000	0.804	S
Lo	Hi	0.875	0.597	S
	Mid	1.000	0.725	S
Hi	Mid	0.125	0.597	

S = Significantly different at this level.

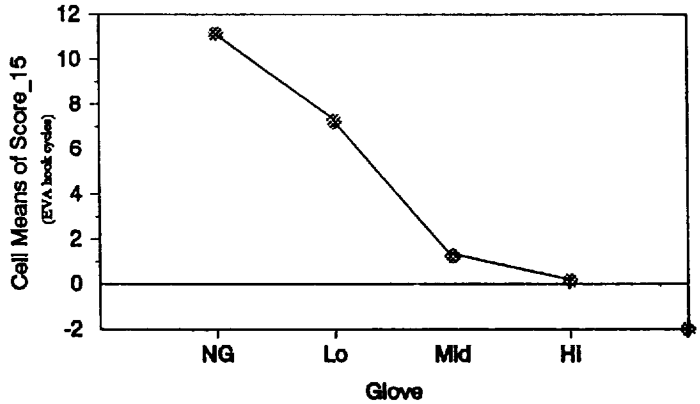
Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Recovery
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
NG	Lo	0.000	0.584	
	Hi	0.125	0.710	
	Mid	0.750	0.786	
Lo	Hi	0.125	0.584	
	Mid	0.750	0.710	S
Hi	Mid	0.625	0.584	S

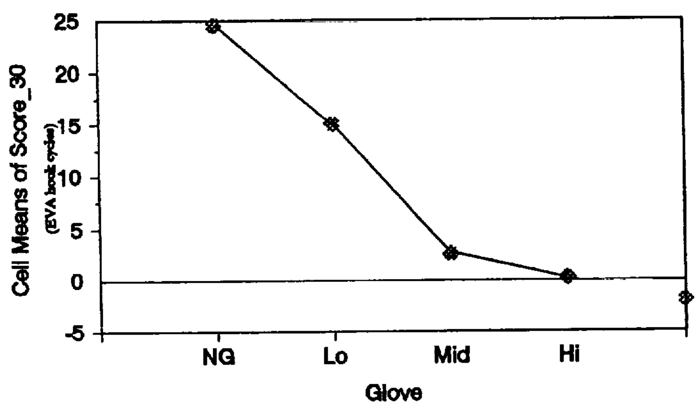
S = Significantly different at this level.

Figure 119. SNK tables for EVA tether performance interactions with GS (continued).

Interaction Plot
Effect: Glove
Dependent: Score_15



Interaction Plot
Effect: Glove
Dependent: Score_30



Interaction Plot
Effect: Glove
Dependent: Score_60

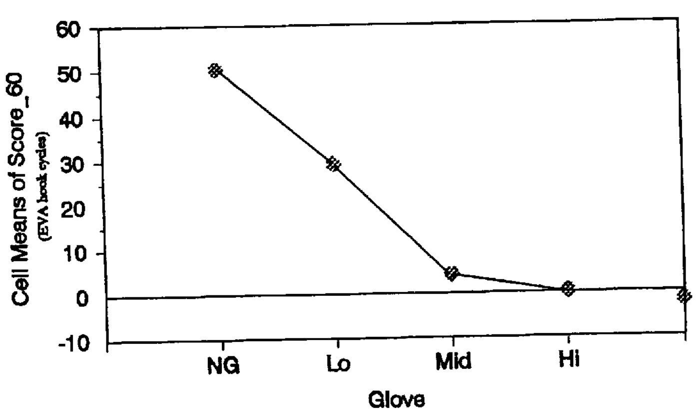
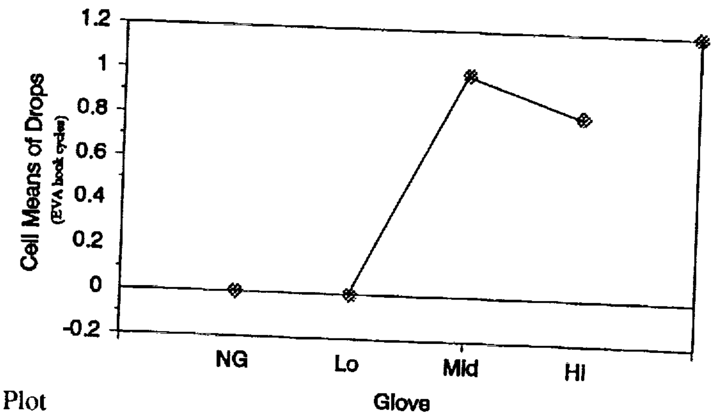


Figure 120. EVA tether test graphs of cell means.

Interaction Plot
Effect: Glove
Dependent: Drops



Interaction Plot
Effect: Glove
Dependent: Recovery

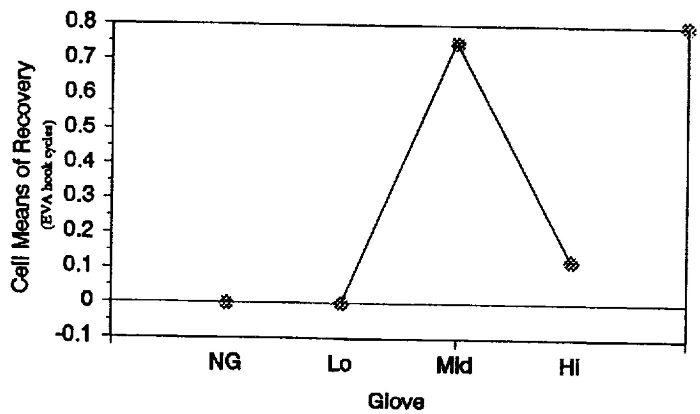


Figure 120. EVA tether test graphs of cell means (continued).

Means Table
Effect: Glove * Strength
Dependent: Score_15

	Count	Mean	Std. Dev.	Std. Error
NG,Lo	4	8.250	2.217	1.109
NG,Hi	4	14.000	3.367	1.683
Lo,Lo	4	3.000	2.000	1.000
Lo, Hi	4	11.500	4.655	2.327
Mid, Lo	4	0.250	0.500	0.250
Mid, Hi	4	2.250	0.957	0.479
Hi, Lo	4	0.000	0.000	0.000
Hi, Hi	4	0.250	0.500	0.250

Means Table
Effect: Glove * Strength
Dependent: Score_30

	Count	Mean	Std. Dev.	Std. Error
NG,Lo	4	17.500	3.697	1.848
NG,Hi	4	31.500	3.786	1.893
Lo,Lo	4	8.000	4.082	2.041
Lo, Hi	4	22.000	7.071	3.536
Mid, Lo	4	1.000	1.155	0.577
Mid, Hi	4	4.250	1.708	0.854
Hi, Lo	4	0.000	0.000	0.000
Hi, Hi	4	0.500	0.577	0.289

Means Table
Effect: Glove * Strength
Dependent: Score_60

	Count	Mean	Std. Dev.	Std. Error
NG,Lo	4	40.500	8.226	4.113
NG,Hi	4	60.250	5.439	2.720
Lo,Lo	4	17.750	7.136	3.568
Lo, Hi	4	40.750	13.301	6.651
Mid, Lo	4	1.250	0.957	0.479
Mid, Hi	4	6.750	3.202	1.601
Hi, Lo	4	0.000	0.000	0.000
Hi, Hi	4	0.500	0.577	0.289

Figure 121. EVA tither means table of GS * Strength.

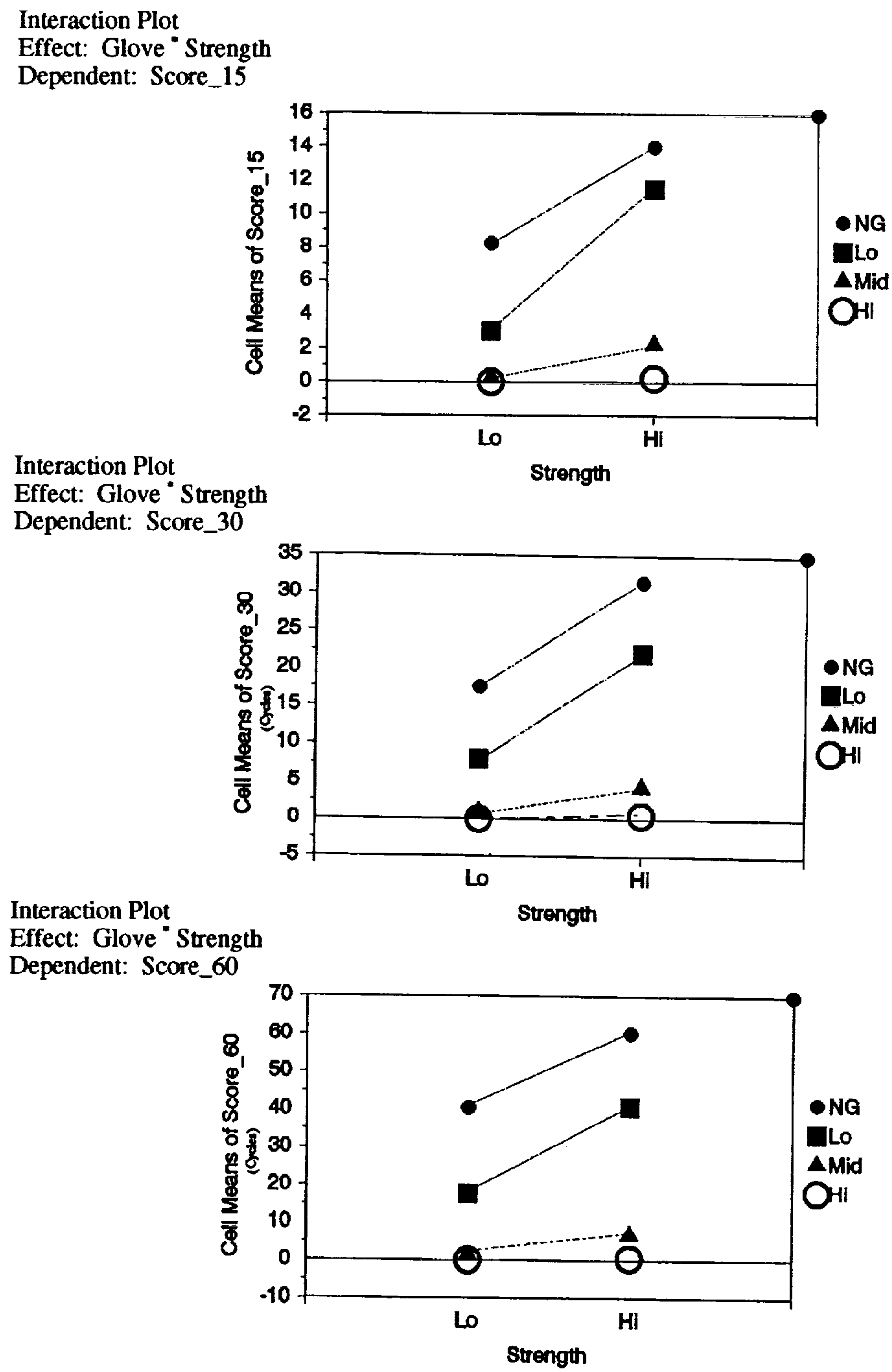


Figure 122. Graph of cell mean versus strength for GS conditions.

Interaction plots of Glove * Strength interactions are presented in figure 122. The SNK calculations for this interaction are presented in figure 123 for 15, 30 and 60 s. CD indicates the critical difference which must be exceeded to indicate a significant effect for that **r** value.

EVA Tether: Glove * Strength at 15 s.

	0.000	0.250	0.250	2.250	3.000	8.250	11.500	14.000
0.000	0.000	0.250	0.250	2.250	3.000	8.250	11.500	14.000
0.250		0.000	0.000	2.000	2.750	8.000	11.250	13.750
0.250			0.000	2.000	2.750	8.000	11.250	13.750
2.250				0.000	0.750	6.000	9.250	11.750
3.000					0.000	5.250	8.500	11.000
8.250						0.000	3.250	5.750
11.500							0.000	2.500
14.000								0.000
'alpha=0.05	'df=18		q	MS	F12=MS/n	sqrt(f12)	CD	
'r=2	2.97		2.97	4.208	10.052	1.025671	3.046241	
'r=3	3.61		3.61	4.208	10.052	1.025671	3.702671	
'r=4	4.00		4.00	4.208	10.052	1.025671	4.102682	
'r=5	4.28		4.28	4.208	10.052	1.025671	4.38987	
'r=6	4.49		4.49	4.208	10.052	1.025671	4.605261	
'r=7	4.67		4.67	4.208	10.052	1.025671	4.789881	
'r=8	4.82		4.82	4.208	10.052	1.025671	4.943732	

EVA Tether: Glove * Strength at 30 s.

	0.000	0.500	1.000	4.250	8.000	17.500	22.000	31.500
0.000	0.000	0.500	1.000	4.250	8.000	17.500	22.000	31.500
0.500		0.000	0.500	3.750	7.500	17.000	21.500	31.000
1.000			0.000	3.250	7.000	16.500	21.000	30.500
4.250				0.000	3.750	13.250	17.750	27.250
8.000					0.000	9.500	14.000	23.500
17.500						0.000	4.500	14.000
22.000							0.000	9.500
31.500								0.000
'alpha=0.05	'df=18		q	MS	F12=MS/n	sqrt(f12)	CD	
'r=2	2.97		2.97	10.128	2.532	1.591226	4.72594	
'r=3	3.61		3.61	10.128	2.532	1.591226	5.74432	
'r=4	4.00		4.00	10.128	2.532	1.591226	6.36490	
'r=5	4.28		4.28	10.128	2.532	1.591226	6.81044	
'r=6	4.49		4.49	10.128	2.532	1.591226	7.14460	
'r=7	4.67		4.67	10.128	2.532	1.591226	7.43102	
'r=8	4.82		4.82	10.128	2.532	1.591226	7.66970	

Figure 123. EVA tether test SNK calculations for GS * Strength.

EVA Tether: Glove * Strength at 60 s.

	0.000	0.500	1.250	6.750	17.750	40.500	40.750	60.250
0.000	0.000	0.500	1.250	6.750	17.750	40.500	40.750	60.250
0.500		0.000	0.750	6.250	17.250	40.000	40.250	59.750
1.250			0.000	5.500	16.500	39.250	39.500	59.000
6.750				0.000	11.000	33.750	34.000	53.500
17.750					0.000	22.750	23.000	42.500
40.500						0.000	0.250	19.750
40.750							0.000	19.500
60.250								0.000
'alpha=0.05	'df=18		q	MS	F12=MS/n	sqrt(f12)	CD	
'r=2	2.97		2.97	43.212	10.803	3.286792	9.76177	
'r=3	3.61		3.61	43.212	10.803	3.286792	11.8655	
'r=4	4.00		4.00	43.212	10.803	3.286792	13.1471	
'r=5	4.28		4.28	43.212	10.803	3.286792	14.0674	
'r=6	4.49		4.49	43.212	10.803	3.286792	14.7576	
'r=7	4.67		4.67	43.212	10.803	3.286792	15.3493	
'r=8	4.82		4.82	43.212	10.803	3.286792	15.8423	

Figure 123. EVA tether test SNK calculations for GS * Strength (continued).

Integrated Task: Pliers

The Score_15, 30, and 60 columns in figure 124 represent cycles completed in 15, 30 and 60 s, respectively.

INTEGRATED TASK: PLIERS TOOL DATA RAW SUBJECT DATA	Subject	Strength	Glove	Run	Score_15	Score_30	Score_60
•Type:	Category	Category	Category	Category	Integer	Integer	Integer
•Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
•Class:	Nominal	Nominal	Nominal	Nominal	Continuous	Continuous	Continuous
•Format:	*	*	*	*	*	*	*
•Dec. Places:	*	*	*	*	*	*	*
Mean:	*	*	*	*			
Std. Deviation:	*	*	*	*			
Std. Error:	*	*	*	*			
Variance:	*	*	*	*			
Coeff. of Variation:	*	*	*	*			
Minimum:	S1	Lo	NG	R1			
Maximum:	S15	Hi	Hi	R4			
Range:	7.000	1.00	3.000	3.000			
Count:	32	32	32	32	32	32	32
Missing Cells:	-	0	0	0	0	0	0
Sum:	*	*	*	*			
Sum of Squares:	*	*	*	*			
	S1	Hi	Hi	R1	2.0	2.0	20
	S1	Hi	NG	R2	21.0	43.0	91.0
	S1	Hi	Mid	R3	3.0	6.0	18.0
	S1	Hi	Lo	R4	10.0	18.0	31.0
	S9	Hi	Mid	R1	1.0	3.0	9.0
	S9	Hi	Hi	R2	0.5	.5	9.0
	S9	Hi	Lo	R3	7.0	20.0	40.0
	S9	Hi	NG	R4	21.0	41.0	79.0
	S11	Hi	Lo	R1	6.0	13.0	25.0
	S11	Hi	Mid	R2	3.5	6.0	12.0
	S11	Hi	NG	R3	15.0	29.0	54.0
	S11	Hi	Hi	R4	2.5	5.5	8.0
	S13	Hi	NG	R1	16.0	31.0	66.0
	S13	Hi	Lo	R2	4.0	7.0	11.0
	S13	Hi	Hi	R3	0.0	1.0	1.0
	S13	Hi	Mid	R4	3.5	14.0	18.0
	S5	Lo	Lo	R1	6.0	12.0	24.0
	S5	Lo	Mid	R2	5.5	11.0	21.0
	S5	Lo	NG	R3	12.0	19.0	34.0
	S5	Lo	Hi	R4	5.5	12.0	27.0
	S12	Lo	NG	R1	11.0	18.0	37.0
	S12	Lo	Lo	R2	3.0	7.0	11.5
	S12	Lo	Hi	R3	2.0	4.0	4.0
	S12	Lo	Mid	R4	4.0	8.0	14.0
	S6	Lo	Mid	R1	2.0	3.0	5.0
	S6	Lo	Hi	R2	2.0	4.0	4.0
	S6	Lo	Lo	R3	7.0	14.0	38.5
	S6	Lo	NG	R4	15.0	32.0	65.0
	S15	Lo	Hi	R1	0.0	0.0	0.0
	S15	Lo	NG	R2	7.0	18.0	38.0
	S15	Lo	Mid	R3	5.5	7.0	16.5
	S15	Lo	Lo	R4	4.0	8.0	19.0

Figure 124. Pliers task data

MODEL OF TOOL TASK PERFORMANCE OVER RUNS

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	18.758	18.758	2.505	0.1645	Subject (Strength)
Subject (Strength)	6	44.922	7.487			
Run	3	34.586	11.529	0.225	0.8776	Run * Subject (Strength)
Run * Strength	3	11.586	3.862	0.075	0.9724	Run * Subject (Strength)
Run * Subject (Strength)	18	921.391	51.188			
Residual	0	3.306E-18	*			

Dependent: Score_15

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	124.031	124.031	5.480	0.0578	Subject (Strength)
Subject (Strength)	6	135.812	22.635			
Run	3	218.281	72.760	0.366	0.7782	Run * Subject (Strength)
Run * Strength	3	2.781	.927	0.005	0.9995	Run * Subject (Strength)
Run * Subject (Strength)	18	3576.562	198.698			
Residual	0	1.416E-16	*			

Dependent: Score_30

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	416.883	416.883	2.971	0.1355	Subject (Strength)
Subject (Strength)	6	841.797	140.299			
Run	3	565.398	188.466	0.226	0.8767	Run * Subject (Strength)
Run * Strength	3	104.273	34.758	0.042	0.9882	Run * Subject (Strength)
Run * Subject (Strength)	18	14978.391	832.133			
Residual	0	30.053E-16	*			

Dependent: Score_60

Figure 125. Pliers test model; interactions with runs.

MODEL OF TOOL TASK PERFORMANCE OVER GS

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	18.758	18.758	2.505	0.1645	Subject (Strength)
Subject (Strength)	6	44.922	7.487			
Glove	3	795.398	265.133	59.830	0.0001	Glove * Subject (Strength)
Glove * Strength	3	92.398	30.799	6.950	0.0026	Glove * Subject (Strength)
Glove * Subject (Strength)	18	79.766	4.431			
Residual	0	2.732E-17	*			

Dependent: Score_15

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	124.031	124.031	5.480	0.0578	Subject (Strength)
Subject (Strength)	6	135.812	22.635			
Glove	3	2986.844	995.615	37.536	0.0001	Glove * Subject (Strength)
Glove * Strength	3	333.344	111.115	4.189	0.0205	Glove * Subject (Strength)
Glove * Subject (Strength)	18	477.438	26.524			
Residual	0	-1.019E-17	*			

Dependent: Score_30

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	416.883	416.883	2.971	0.1355	Subject (Strength)
Subject (Strength)	6	841.797	140.299			
Glove	3	12242.398	4080.799	35.181	0.0001	Glove * Subject (Strength)
Glove * Strength	3	1317.773	439.258	3.787	0.0288	Glove * Subject (Strength)
Glove * Subject (Strength)	18	2087.891	115.994			
Residual	0	6.566E-16	*			

Dependent: Score_60

Figure 126. Pliers task model; interactions with GS.

Means Table
Effect: Glove
Dependent: Score_15

	Count	Mean	Std. Dev.	Std. Error
NG	8	14.750	4.803	1.698
Lo	8	5.875	2.232	0.789
Mid	8	3.500	1.558	0.551
Hi	8	1.812	1.792	0.633

Means Table
Effect: Glove
Dependent: Score_30

	Count	Mean	Std. Dev.	Std. Error
NG	8	28.875	9.963	3.523
Lo	8	12.375	4.926	1.742
Mid	8	7.250	3.770	1.333
Hi	8	3.625	3.898	1.378

Means Table
Effect: Glove
Dependent: Score_60

	Count	Mean	Std. Dev.	Std. Error
NG	8	58.000	20.963	7.411
Lo	8	25.000	11.074	3.915
Mid	8	14.188	5.305	1.875
Hi	8	6.875	8.725	3.085

Figure 127. Pliers task means for GS.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_15
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Hi	Mid	1.688	2.210	
	Lo	4.062	2.687	S
	NG	12.938	2.977	S
Mid	Lo	2.375	2.210	S
	NG	11.250	2.687	S
Lo	NG	8.875	2.210	S

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_30
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Hi	Mid	3.625	5.408	
	Lo	8.750	6.573	S
	NG	25.250	7.283	S
Mid	Lo	5.125	5.408	
	NG	21.625	6.573	S
Lo	NG	16.500	5.408	S

S = Significantly different at this level.

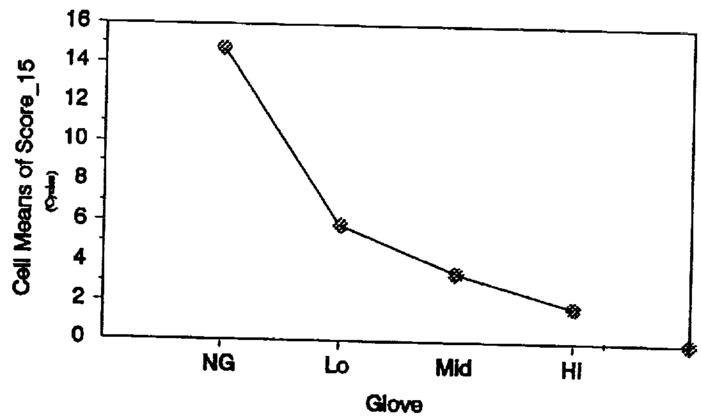
Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Subject Strength
Dependent: Score_60
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Hi	Mid	7.312	11.309	
	Lo	18.125	13.746	S
	NG	51.125	15.231	S
Mid	Lo	10.812	11.309	
	NG	43.812	13.746	S
Lo	NG	33.000	11.309	S

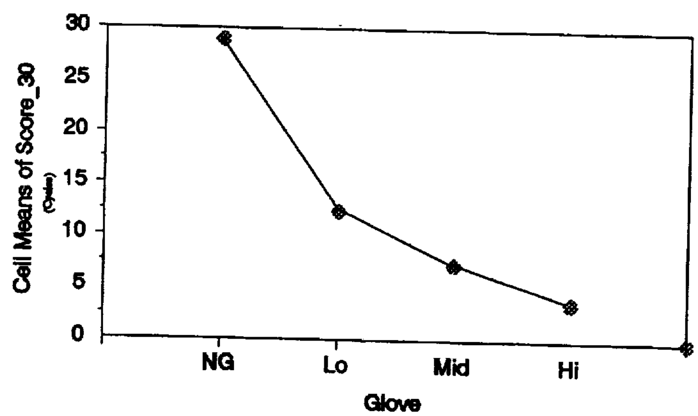
S = Significantly different at this level.

Figure 128. Pliers task SNK for GS.

Interaction Plot
Effect: Glove
Dependent: Score_15



Interaction Plot
Effect: Glove
Dependent: Score_30



Interaction Plot
Effect: Glove
Dependent: Score_60

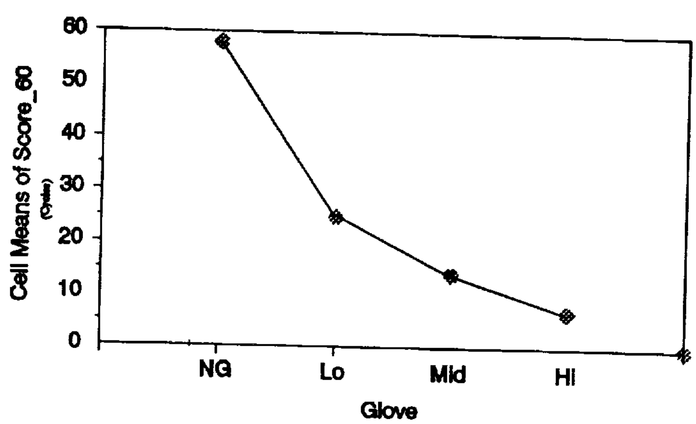


Figure 129. Graphs of pliers means versus GS.

Means Table
Effect: Glove * Strength
Dependent: Score_15

	Count	Mean	Std. Dev.	Std. Error
NG,Lo	4	11.250	3.304	1.652
NG,Hi	4	18.250	3.202	1.601
Lo,Lo	4	5.000	1.826	.913
Lo, Hi	4	6.750	2.500	1.250
Mid, Lo	4	4.250	1.658	.829
Mid, Hi	4	2.750	1.190	.595
Hi, Lo	4	2.375	2.287	1.143
Hi, Hi	4	1.250	1.190	.595

Means Table
Effect: Glove * Strength
Dependent: Score_30

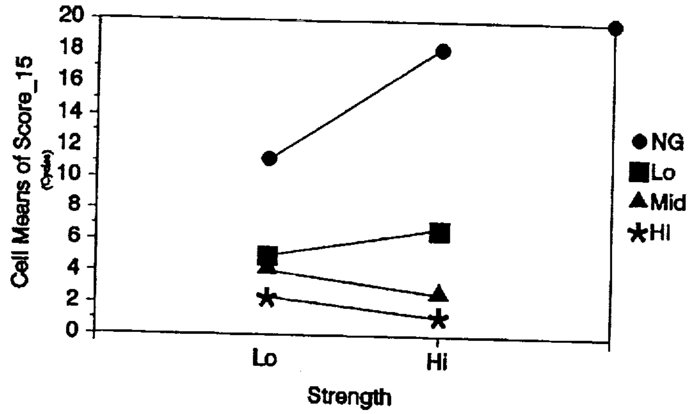
	Count	Mean	Std. Dev.	Std. Error
NG,Lo	4	21.750	6.850	3.425
NG,Hi	4	36.000	7.024	3.512
Lo,Lo	4	10.250	3.304	1.652
Lo, Hi	4	14.500	5.802	2.901
Mid, Lo	4	7.250	3.304	1.652
Mid, Hi	4	7.250	4.717	2.358
Hi, Lo	4	5.000	5.033	2.517
Hi, Hi	4	2.250	2.255	1.127

Means Table
Effect: Glove * Strength
Dependent: Score_60

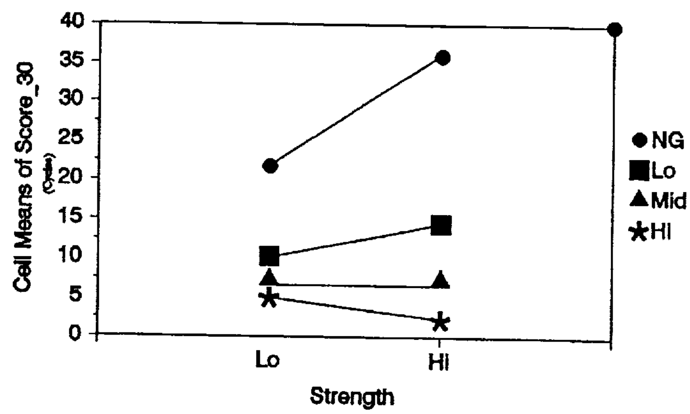
	Count	Mean	Std. Dev.	Std. Error
NG,Lo	4	43.500	14.434	7.217
NG,Hi	4	72.500	16.010	8.005
Lo,Lo	4	23.250	11.391	5.695
Lo, Hi	4	26.750	12.176	6.088
Mid, Lo	4	14.125	6.738	3.369
Mid, Hi	4	14.250	4.500	2.250
Hi, Lo	4	8.750	12.312	6.156
Hi, Hi	4	5.000	4.082	2.041

Figure 130. Pliers means table for Glove * Strength.

Interaction Plot
Effect: Glove * Strength
Dependent: Score_15



Interaction Plot
Effect: Glove * Strength
Dependent: Score_30



Interaction Plot
Effect: Glove * Strength
Dependent: Score_60

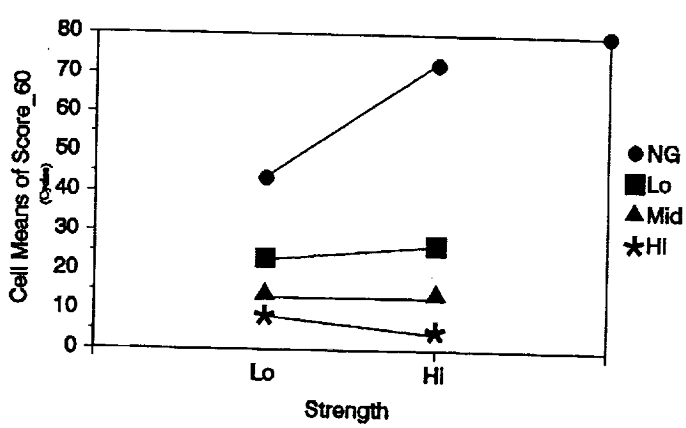


Figure 131. Graphs of pliers means versus Strength for GS.

Fatigue

Score_1/4 and Score_1/2 refer to times at which subjects grip gauge values reached one-fourth and one-hald of their maximum grip value.

FATIGUE TEST SUBJECT DATA RAW SUBJECT DATA						
	Subject	**Strength**	**Glove**	**Run**	**Score_1\4**	**Score_1\2**
• Type:	Category	Category	Category	Category	Category	Real
• Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
• Class:	Nominal	Nominal	Nominal	Nominal	Nominal	Continuous
• Format:	*	*	*	*	*	Free Format Fl...
• Dec. Places:	*	*	*	*	*	1
Mean:	*	*	*	*	*	4.0
Std. Deviation:	*	*	*	*	*	3.0
Std. Error:	*	*	*	*	*	.3
Variance:	*	*	*	*	*	8.8
Coeff. of Variation:	*	*	*	*	*	74.0
Minimum:	S1	Lo	NG	R1	G0.5	0.0
Maximum:	S15	Hi	Hi	R4	G1.5	16.0
Range:	7.000	1.000	3.000	3.000	2.000	16.0
Count:	32	32	32	32	96	96
Missing Cells:	0	0	0	0	0	0
Sum:	*	*	*	*	*	384.0
Sum of Squares:	*	*	*	*	*	2367.5
	S1	Hi	Hi	R1	35.0	69.0
	S1	Hi	NG	R2	32.0	52.0
	S1	Hi	Mid	R3	12.0	30.0
	S1	Hi	Lo	R4	27.0	48.0
	S9	Hi	Mid	R1	105.0	121.0
	S9	Hi	Hi	R2	52.0	79.0
	S9	Hi	Lo	R3	70.0	133.0
	S9	Hi	NG	R4	128.0	202.0
	S11	Hi	Lo	R1	26.0	49.0
	S11	Hi	Mid	R2	49.0	59.0
	S11	Hi	NG	R3	33.0	72.0
	S11	Hi	Hi	R4	59.0	63.0
	S13	Hi	NG	R1	14.0	52.0
	S13	Hi	Lo	R2	32.0	90.0
	S13	Hi	Hi	R3	10.0	12.0
	S13	Hi	Mid	R4	42.0	68.0
	S5	Lo	Lo	R1	59.0	64.0
	S5	Lo	Mid	R2	35.0	48.0
	S5	Lo	NG	R3	39.0	51.0
	S5	Lo	Hi	R4	66.0	78.0
	S12	Lo	NG	R1	25.0	84.0
	S12	Lo	Lo	R2	51.0	108.0
	S12	Lo	Hi	R3	21.0	34.0
	S12	Lo	Mid	R4	95.0	128.0
	S6	Lo	Mid	R1	9.0	12.0
	S6	Lo	Hi	R2	30.0	42.0
	S6	Lo	Lo	R3	8.0	18.0
	S6	Lo	NG	R4	32.0	85.0
	S15	Lo	Hi	R1	24.0	32.0
	S15	Lo	NG	R2	7.0	22.0
	S15	Lo	Mid	R3	26.0	56.0
	S15	Lo	Lo	R4	25.0	31.0

Figure 132. Fatigue test data.

FATIGUE MODEL

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	946.125	946.125	.404	.5486	Subject (Strength)
Subject (Strength)	6	14059.750	2343.292			
Glove	3	490.125	163.375	.330	.8039	Glove * Subject (Strength)
Glove * Strength	3	683.125	227.708	.460	.7139	Glove * Subject (Strength)
Glove * Subject (Strength)	18	8916.750	495.375			
Residual	0	-1.110E-16	*			

Dependent: Score_1/4

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	2926.125	2926.125	.680	.4412	Subject (Strength)
Subject (Strength)	6	25830.875	4305.146			
Glove	3	2841.250	947.083	.959	.4332	Glove * Subject (Strength)
Glove * Strength	3	926.625	308.875	.313	.8158	Glove * Subject (Strength)
Glove * Subject (Strength)	18	17768.625	987.145			
Residual	0	2.109E-15	*			

Dependent: Score_1/2

Figure 133. Fatigue models at one-fourth and one-half maximum value.

Comfort

Hand comfort test data is presented in figures 134 and 135. Test data was collected from the Hand Comfort Questionnaire presented in appendix B. A model was run to compare all GS conditions and only the three gloved states. Regions 1 through 7 refer to the thumb, index through little fingers, palm, and back of hand respectively. Models of comfort averages for the overall hand are presented in figures 140 and 145.

HAND COMFORT
RAW SUBJECT DATA

	Subject	Strength	Glove	Run	Score_1	Score_2	Score_3	Score_4	Score_5	Score_6	Score_7
▴Type:	Category	Category	Category	Category	Integer	Integer	Integer	Integer	Integer	Integer	Integer
▴Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
▴Class:	Nominal	Nominal	Nominal	Nominal	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
▴Format:	*	*	*	*	*	*	*	*	*	*	*
▴Dec. Places:	*	*	*	*	*	*	*	*	*	*	*
Mean:	*	*	*	*	1.312	1.281	1.125	1.156	1.562	1.594	2.344
Std. Deviation:	*	*	*	*	.592	.772	.336	.369	1.162	1.160	1.208
Std. Error:	*	*	*	*	.105	.136	.059	.065	.205	.205	.214
Variance:	*	*	*	*	.351	.596	.113	.136	1.351	1.346	1.459
Coeff. of Variation:	*	*	*	*	45.127	60.243	29.868	31.905	74.383	72.789	51.531
Minimum:	S9	Hi	NG	R1	1	1	1	1	1	1	1
Maximum:	S15	Lo	Hi	R4	3	5	2	2	5	5	5
Range:	7.000	1.000	3.000	3.000	2.000	4.000	1.000	1.000	4.000	4.000	4.000
Count:	32	32	32	32	32	32	32	32	32	32	32
Missing Cells:	0	0	0	0	0	0	0	0	0	0	0
Sum:	*	*	*	*	42.000	41.000	36.000	37.000	50.000	51.000	75.000
Sum of Squares:	*	*	*	*	66.000	71.000	44.000	47.000	120.000	123.000	221.000
	S9	Hi	Mid	R1	1	1	1	2	3	5	3
	S9	Hi	Hi	R2	2	2	2	2	3	3	3
	S9	Hi	Lo	R3	1	1	1	1	1	1	2
	S9	Hi	NG	R4	1	1	1	1	1	1	1
	S1	Hi	Mid	R3	1	1	1	1	1	1	2
	S1	Hi	Hi	R1	1	1	1	1	1	1	2
	S1	Hi	Lo	R4	1	1	1	1	1	1	1
	S1	Hi	NG	R2	1	1	1	1	1	1	1
	S11	Hi	Lo	R1	1	2	2	2	2	2	3
	S11	Hi	Mid	R2	1	1	1	1	1	2	3
	S11	Hi	NG	R3	1	1	1	1	1	1	1

Figure 134. Hand comfort test data—all GS conditions.

HAND COMFORT
RAW SUBJECT DATA

	Subject	Strength	Glove	Run	Score_1	Score_2	Score_3	Score_4	Score_5	Score_6	Score_7
	S11	Hi	Hi	R4	1	1	2	2	1	4	4
	S13	Hi	NG	R1	1	1	1	1	1	1	1
	S13	Hi	Lo	R2	2	2	2	2	2	1	4
	S13	Hi	Hi	R3	1	5	1	1	5	5	5
	S13	Hi	Mid	R4	1	1	1	1	1	1	1
	S6	Lo	Mid	R1	1	1	1	1	1	1	2
	S6	Lo	Hi	R2	1	1	1	1	2	1	3
	S6	Lo	R3	R3	2	2	1	1	1	1	1
	S6	Lo	NF4	R4	1	1	1	1	1	1	1
	S5	Lo	Lo	R1	3	1	1	1	1	1	3
	S5	Lo	Mid	R2	1	1	1	1	1	1	4
	S5	Lo	NG	R3	1	1	1	1	1	1	1
	S5	Lo	Hi	R4	1	1	1	1	1	1	4
	S12	Lo	NG	R1	1	1	1	1	1	1	1
	S12	Lo	Lo	R2	2	2	1	1	1	1	3
	S12	Lo	Hi	R3	1	1	1	1	5	1	3
	S12	Lo	Mid	R4	3	1	1	1	4	1	4
	S15	Lo	Hi	R1	2	1	1	1	1	2	3
	S15	Lo	NG	R2	1	1	1	1	1	1	1
	S15	Lo	Mid	R3	2	1	1	1	1	3	2
	S15	Lo	Lo	R4	1	1	1	1	1	2	2

Figure 134. Hand comfort test data—all GS conditions (continued).

HAND COMFORT
RAW SUBJECT DATA
COMPARISON OF GLOVED STATES ONLY

	Subject	Strength	Glove	Score_1	Score_2	Score_3	Score_4	Score_5	Score_6	Score_7
▲Type:	Category	Category	Category	Integer	Integer	Integer	Integer	Integer	Integer	Integer
▲Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
▲Class:	Nominal	Nominal	Nominal	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
▲Format:	*	*	*	*	*	*	*	*	*	*
▲Dec. Places:	*	*	*	*	*	*	*	*	*	*
Mean:	*	*	*	1.417	1.375	1.167	1.208	1.750	1.792	2.792
Std. Deviation:	*	*	*	.654	.875	.381	.415	1.294	1.285	1.062
Std. Error:	*	*	*	.133	.179	.078	.085	.264	.262	.217
Variance:	*	*	*	.428	.766	.145	.172	1.674	1.650	1.129
Coeff. of Variation:	*	*	*	46.155	63.665	32.631	34.333	73.931	71.702	38.055
Minimum:	S9	Hi	Lo	1	1	1	1	1	1	1
Maximum:	S15	Lo	Hi	3	5	2	2	5	5	5
Range:	7.000	1.000	2.000	2.000	4.000	1.000	1.000	4.000	4.000	4.000
Count:	24	24	24	24	24	24	24	24	24	24
Missing Cells:	0	0	0	0	0	0	0	0	0	0
Sum:	*	*	*	34.000	33.000	28.000	29.000	42.000	43.000	67.000
Sum of Squares:	*	*	*	58.000	63.000	36.000	39.000	112.000	115.000	213.000
	S9	Hi	Mid	1	1	1	2	3	5	3
	S9	Hi	Hi	2	2	2	2	3	3	3
	S9	Hi	Lo	1	1	1	1	1	1	2
	S1	Hi	Mid	1	1	1	1	1	1	2
	S1	Hi	Hi	1	1	1	1	1	1	2
	S1	Hi	Lo	1	1	1	1	1	1	1
	S11	Hi	Lo	1	2	2	2	2	2	3
	S11	Hi	Mid	1	1	1	1	1	2	3
	S11	Hi	Hi	1	1	2	2	1	4	4

Figure 135. Hand comfort test data—Lo, Mid, Hi GS conditions only.

HAND COMFORT
RAW SUBJECT DATA
COMPARISON OF GLOVED STATES ONLY

	Subject	Strength	Glove	Score_1	Score_2	Score_3	Score_4	Score_5	Score_6	Score_7
	S13	Hi	Lo	2	2	2	2	2	1	4
	S13	Hi	Hi	1	5	1	1	5	5	5
	S13	Hi	Mid	1	1	1	1	1	1	1
	S6	Lo	Mid	1	1	1	1	1	1	2
	S6	Lo	Hi	1	1	1	1	2	1	3
	S6	Lo	Lo	2	2	1	1	1	1	1
	S5	Lo	Lo	3	1	1	1	1	1	3
	S5	Lo	Mid	1	1	1	1	1	1	4
	S5	Lo	Hi	1	1	1	1	1	1	4
	S12	Lo	Lo	2	2	1	1	1	1	3
	S12	Lo	Hi	1	1	1	1	5	1	3
	S12	Lo	Mid	3	1	1	1	4	1	4
	S15	Lo	Hi	2	1	1	1	1	2	3
	S15	Lo	Mid	2	1	1	1	1	3	2
	S15	Lo	Lo	1	1	1	1	1	2	2

Figure 135. Hand comfort test data—Lo, Mid, Hi GS conditions only (continued).

COMFORT MODEL

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	1.125	1.125	9.000	0.0240	Subject (Strength)
Subject (Strength)	6	0.750	0.125			
Glove	3	1.625	0.542	1.560	0.2337	Glove * Subject (Strength)
Glove * Strength	3	1.125	0.375	1.080	0.3826	Glove * Subject (Strength)
Glove * Subject (Strength)	18	6.250	0.347			
Residual	0	4.337E-19	*			

Dependent: Score_1

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.781	0.781	1.190	0.3171	Subject (Strength)
Subject (Strength)	6	3.938	0.656			
Glove	3	2.594	0.865	1.766	0.1897	Glove * Subject (Strength)
Glove * Strength	3	2.344	0.781	1.596	0.2253	Glove * Subject (Strength)
Glove * Subject (Strength)	18	8.812	0.490			
Residual	0	4.337E-19	*			

Dependent: Score_2

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.500	0.500	6.000	0.0498	Subject (Strength)
Subject (Strength)	6	0.500	0.083			
Glove	3	0.500	0.167	2.000	0.1501	Glove * Subject (Strength)
Glove * Strength	3	0.500	0.167	2.000	0.1501	Glove * Subject (Strength)
Glove * Subject (Strength)	18	1.500	0.083			
Residual	0	-2.755E-40	*			

Dependent: Score_3

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.781	0.781	6.818	0.0401	Subject (Strength)
Subject (Strength)	6	0.688	0.115			
Glove	3	0.344	0.115	1.000	0.4155	Glove * Subject (Strength)
Glove * Strength	3	0.344	0.115	1.000	0.4155	Glove * Subject (Strength)
Glove * Subject (Strength)	18	2.062	0.115			
Residual	0	1.355E-19	*			

Dependent: Score_4

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.125	0.125	0.059	0.8164	Subject (Strength)
Subject (Strength)	6	12.750	2.125			
Glove	3	8.625	2.875	2.620	0.0823	Glove * Subject (Strength)
Glove * Strength	3	0.625	0.208	0.190	0.9019	Glove * Subject (Strength)
Glove * Subject (Strength)	18	19.750	1.097			
Residual	0	1.735E-18	*			

Dependent: Score_5

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	3.781	3.781	2.771	0.1470	Subject (Strength)
Subject (Strength)	6	8.187	1.365			
Glove	3	7.844	2.615	2.842	0.0669	Glove * Subject (Strength)
Glove * Strength	3	5.344	1.781	1.936	0.1600	Glove * Subject (Strength)
Glove * Subject (Strength)	18	16.562	0.920			
Residual	0	2.033E-18	*			

Dependent: Score_6

Figure 136. Hand comfort model.

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.031	0.031	0.022	0.8864	Subject (Strength)
Subject (Strength)	6	8.438	1.406			
Glove	3	23.594	7.865	11.984	0.0002	Glove * Subject (Strength)
Glove * Strength	3	1.344	0.448	0.683	0.5742	Glove * Subject (Strength)
Glove * Subject (Strength)	18	11.812	0.656			
Residual	0	1.952E-18	*			

Dependent: Score_7

Figure 136. Hand comfort model (continued).

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Score_1
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Hi	Lo	0.375	0.306	S

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Score_3
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Lo	Hi	0.250	0.250	S

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Score_04
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Lo	Hi	0.312	0.293	S

S = Significantly different at this level.

Figure 137. Comfort SNK for regions 1, 3, 4 for strength.

Student-Newman-Keuls
Effect: Glove
Error term: Type I sum of squares for Glove * Strength
Dependent: Score_7
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
NG	Lo	1.375	.851	S
	Mid	1.625	1.034	S
	Hi	2.375	1.146	S
Lo	Mid	.250	.851	
	Hi	1.000	1.034	
Mid	Hi	.750	.851	

S = Significantly different at this level.

Figure 138. Comfort SNK for region 7 for GS.

Interaction Plot
Effect: Glove
Dependent: Score_7

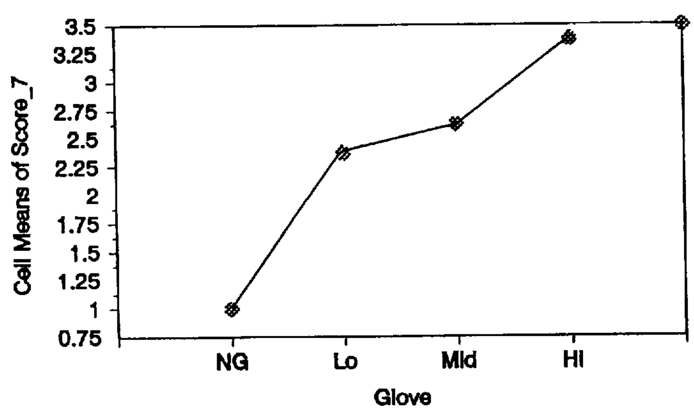


Figure 139. Graph of comfort region 7 means versus GS.

MODEL OF AVERAGE OF AREA COMFORT RATINGS

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.255	0.255	0.843	0.3940	Subject (Strength)
Subject (Strength)	6	1.816	0.303			
Glove	3	3.342	1.114	6.121	0.0047	Glove * Subject (Strength)
Glove * Strength	3	0.730	0.243	1.336	0.2938	Glove * Subject (Strength)
Glove * Subject (Strength)	18	3.276	0.182			
Residual	0	-3.456E-18	*			

Dependent: Overall

Figure 140. Average comfort model.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Glove * Strength
Dependent: Glove
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
NG	Lo	0.500	0.448	S
	Mid	0.518	0.544	
	Hi	0.911	0.603	S
Lo	Mid	0.018	0.448	
	Hi	0.411	0.544	
Mid	Hi	0.393	0.448	

S = Significantly different at this level.

Figure 141. Average comfort SNK for GS.

Interaction Plot
Effect: Glove
Dependent: Overall

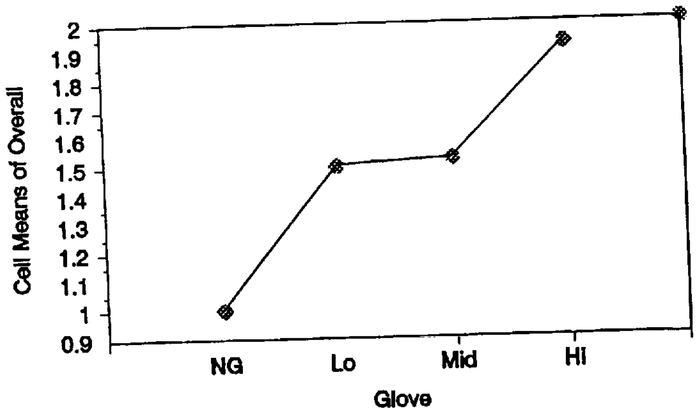


Figure 142. Graph of average comfort means versus GS.

COMFORT MODEL WITHOUT NG CONDITION

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	1.500	1.500125	9.000	0.0240	Subject (Strength)
Subject (Strength)	6	1.000	0.16725			
Glove	2	0.583	0.29542	1.560	0.5731	Glove * Subject (Strength)
Glove * Strength	2	0.750	0.375	1.080	0.4933	Glove * Subject (Strength)
Glove * Subject (Strength)	12	6.000	0.500			
Residual	0	1.073E-17	*			

Dependent: Score_1

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	1.042	1.042	1.190	0.3171	Subject (Strength)
Subject (Strength)	6	5.250	0.875			
Glove	2	1.750	0.875	1.400	0.2841	Glove * Subject (Strength)
Glove * Strength	2	2.083	1.042	1.667	0.2298	Glove * Subject (Strength)
Glove * Subject (Strength)	12	7.500	0.625			
Residual	0	-8.674E-19	*			

Dependent: Score_2

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.667	0.667	6.000	0.0498	Subject (Strength)
Subject (Strength)	6	0.667	0.111			
Glove	2	0.333	0.167	1.500	0.2621	Glove * Subject (Strength)
Glove * Strength	2	0.333	0.167	1.500	0.2621	Glove * Subject (Strength)
Glove * Subject (Strength)	12	1.333	0.111			
Residual	0	1.166E-18	*			

Dependent: Score_3

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	1.042	1.042	6.818	0.0401	Subject (Strength)
Subject (Strength)	6	0.917	0.153			
Glove	2	0.083	0.042	0.273	0.7659	Glove * Subject (Strength)
Glove * Strength	2	0.083	0.042	0.273	0.7659	Glove * Subject (Strength)
Glove * Subject (Strength)	12	1.833	0.153			
Residual	0	-1.666E-18	*			

Dependent: Score_4

Figure 143. Comfort model—Lo, Mid, Hi GS only.

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.167	0.167	0.059	0.8164	Subject (Strength)
Subject (Strength)	6	17.000	2.833			
Glove	2	5.250	2.625	2.032	0.1737	Glove * Subject (Strength)
Glove * Strength	2	0.583	0.292	0.226	0.8012	Glove * Subject (Strength)
Glove * Subject (Strength)	12	15.500	1.292			
Residual	0	-8.430E-19	*			

Dependent: Score_5

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	05.042	5.042	2.771	0.1470	Subject (Strength)
Subject (Strength)	6	10.917	1.819			
Glove	2	4.083	2.042	1.771	0.2118	Glove * Subject (Strength)
Glove * Strength	2	4.083	2.042	1.771	0.2118	Glove * Subject (Strength)
Glove * Subject (Strength)	12	13.833	1.153			
Residual	0	-3.524E-19	*			

Dependent: Score_6

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.042	0.0042	0.022	0.8864	Subject (Strength)
Subject (Strength)	6	11.250	1.875			
Glove	2	4.333	2.167	2.889	0.0946	Glove * Subject (Strength)
Glove * Strength	2	1.333	0.667	0.889	0.4365	Glove * Subject (Strength)
Glove * Subject (Strength)	12	9.000	0.750			
Residual	0	-3.524E-18	*			

Dependent: Score_7

Figure 143. Comfort model—Lo, Mid, Hi GS only (continued).

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Score_1
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Hi	Lo	0.500	0.408	S

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Score_3
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Lo	Hi	0.333	0.333	S

S = Significantly different at this level.

Student-Newman-Keuls
Effect: Strength
Error term: Type I sum of squares for Subject Strength
Dependent: Score_04
Significance level: 0.05

	Versus	Diff.	Crit. diff.	
Lo	Hi	0.417	0.390	S

S = Significantly different at this level.

Figure 144. Comfort SNK for regions 1, 3, 4 for strength—gloved states only.

AVERAGE OF COMFORT - GLOVED STATES ONLY

Type I Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
Strength	1	0.340	0.340	0.843	0.3940	Subject (Strength)
Subject (Strength)	6	2.422	0.404			
Glove	2	0.862	0.431	1.938	0.1865	Glove * Subject (Strength)
Glove * Strength	2	0.845	0.322	1.448	0.2732	Glove * Subject (Strength)
Glove * Subject (Strength)	12	2.670	0.223			
Residual	0	4.601E-18	*			

Dependent: Overall

Figure 145. Average comfort model—gloved states only.

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APPROVAL

EVA GLOVE EVALUATION TEST PROTOCOL

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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