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Extravehicular Activities Limitations Study

Volume II: Establishment Of Physiological & Performance Criteria For EVA Gloves

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FOREWORD

This report (No. AS-EVALS-FR-8701) is submitted by Grumman Space Systems Division (GSSD) to the Lyndon B. Johnson Space Center, NASA as part of the work performed under Contract NAS 9-17702: Extravehicular Activities Limitations Study. The report represents the Final Report as per DRL No. T-2064, Line Item No. 1, DRD No. MA-183TF.

The report is submitted in two volumes. Volume I presents the results of Phase I: "Physiological Limitations to Extravehicular Activity in Space" with the exception of SOW Task 2.8: "Hand mobility, dexterity, and fatigue." Volume II presents the results of Phase II: "Establishment of Physiological and Performance Criteria for EVA Gloves" and Phase I SOW Task 2.8.

The work was performed for NASA under the technical direction of David J. Horrigan (SD5), Head - Environmental Physiology, NASA JSC.

The conclusions and opinions presented in the report are those of the author's alone and are not necessarily consistent with those of NASA or GSSD.

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PREFACE TO VOLUME II

Volume II of the Final Report presents the results of the Phase II effort: "Establishment of the Physiological and Performance Criteria for EVA Gloves" and Task 2.8 of Phase I: "Hand Mobility, Dexterity, and Fatigue."

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ACRONYMS

ACCESS	Assembly Concept for Construction of Erectable Space Structures
BTE	Baltimore Therapeutic Equipment
CMC	Carpometacarpal
DIP	Distal Interphalangeal
DV	Dependent Variable
EASE	Experimental Assembly of Structure in EVA
EMG	Electromyogram
EMU	Extravehicular Mobility Unit
EVA	Extravehicular Activity
IV	Independent Variable
MCP	Metacarpophalangeal
MMU	Manned Manuevering Unit
MVC	Maximum Voluntary Contraction
ORU	Operational Replacement Unit
PIP	Proximal Interphalangeal
ROM	Range of Motion
RTV	Room Temperature Vulcanized
TMG	Thermal Micrometearoid Garment

1 - INTRODUCTION

Human hand capabilities such as dexterity and tactile perception are major factors in man's superiority over automatic or robotic devices for interactive or adaptive EVA tasks. In those cases for which interfaces, procedures, tools, etc, either cannot be defined in advance or become too diverse and complex, man's versatility makes him more effective and efficient than a machine. In the EVA environment, the hand is not only a multi-purpose tool but also the primary means of locomotion, restraint and material handling. However, existing pressure gloves significantly reduce hand dexterity, range of motion, tactility, strength and endurance. In addition, they are uncomfortable - sometimes to the point of pain and/or minor physical injury (bruises, abrasions, loss of nails, etc). In fact, the development of comfortable gloves with improved dexterity and tactility is considered the pacing item in the attainment of an advanced EVA System to meet the needs of the Space Station.

The conflicts associated with providing hand protection while permitting adequate hand functioning has been widely recognized. Roebuch, Kroemer, and Thompson(1) noted that "the combination of anthropometric and engineering aspects of glove design is one of the most fascinating and difficult problems in engineering clothing. Not only must the glove provide protection but ideally it should also permit dexterity and a wide range of pressure (i.e., "feel") for tactile sensation. These requirements often work against each other, resulting in a variety of compromises."

Few items of protective clothing are required to meet more stringent requirements than EVA gloves. They must provide pressure containment (currently at 4.3 psid), thermal insulation for contact with extremely hot or cold surfaces (-150°F to +250°F) and temperature imposed by the environment, solar radiation, cut/tear strength, abrasion resistance, and micrometeoroid shielding. Simultaneously, they are expected to accommodate finger/hand/wrist motions, provide reasonable tactility, dexterity and comfort, withstand substantial workloads and abrasion, and impose minimal resistance on the user. Current gloves have demonstrated a remarkable degree of safety and reliability in pressure integrity and thermal/micrometeoroid protection, but not without compromises in dexterity, tactility, comfort and reduced user workload.

This report describes the results of a study to:

- Review results of previous investigations of EVA gloved hand performance
- Design test methods and protocols to evaluate human hand performance capabilities such as range of motion, strength, tactile perception, dexterity, fatigue, and comfort
- Evaluate tests and collect a database of information on performance of the bare and EVA gloved hand using the methods developed.

Section 1 of the report discusses our conceptual approach to the analysis of hand capabilities and the factors that affect hand performance. Section 2 of this report reviews data in the literature on these relationships with special emphasis on EVA and pressure glove effects. Section 3 presents objectives of the study. Section 4 details the methodology used to develop tests of hand capabilities and details the experimental methodology employed to assess the impact on those capabilities of the factors listed above. Section 5 presents detailed results of the test program and Section 6 presents a summary of the results and conclusions from the investigation.

1.1 HAND PERFORMANCE VARIABLES

Six basic hand capability categories were identified for assessment in this study; range of motion, strength, tactility, dexterity, fatigue, and comfort. Each category was further divided into individual parameters of interest. The parameters are identified in this section and are discussed more fully in Subsection 4.3 Basic Capability Tests and Procedures. The identification of assessment methods of hand capabilities were based upon these individual parameters. Two things should be noted about this conceptual breakdown of basic hand capabilities. First, with respect to human performance measurement, the hand operates as an integrated system, hence the categories are not mutually exclusive. That is, performance in a particular category is affected by other categories. These categories, therefore, represent functional domains of performance. Second, the parameters listed under each category are not all inclusive. Each parameter was selected because it satisfied either one of two criteria: (1) the parameter was a widely accepted indicator of the category, or (2) the parameter was especially relevant to EVA hand activity or glove design.

The six categories of hand capability can be divided into two groups (see Table 1-1). The first group, referred to as Level 1, are those performance capabilities that are directly tied to major subdivisions of hand physiology/anatomy. These categories are range of motion, strength, and tactile perception. The range of motion of the thumb, fingers, and wrist is limited mainly by hand anatomy including restrictions on the mechanics of joint motion imposed by the joint surfaces, joint capsule, ligaments and tendons. The strength of the fingers and hand are determined not only by the muscle masses in the hand but the forearm as well and the orientation of their tendinous attachments. The action of these physiological elements is expressed in the finger's and hand's capability to produce forces and torques. Finally, the tactile perception of the fingers and hand is determined mainly by the types and number of sensory nerve endings. Tactile perception has two functional components: cutaneous sense and kinesthesis(2). Cutaneous sense refers to the sensation and perception of the physical environment, such as surface texture and temperature, caused by stimulation of cutaneous sensory elements. Kinesthesis refers to the awareness of body position associated with motor memory and proprioception. Emphasis in this study is on cutaneous sense in the areas of cutaneous sensitivity resolution, object shape and size perception/discrimination, and tactile feedback.

The second group of categories, referred to as Level 2, are more complex and represent integration of Level 1 capabilities as well as additional physiological and psychological capabilities. Level 2 capabilities are, therefore, multidimensional and, unlike Level 1 capabilities, not principally associated with single physiological/ anatomical elements of the hand. They include dexterity, fatigue, and comfort.

Dexterity depends on integration of range of motion, strength, and sensory input (and training as well). The latter consists of either tactile cues, visual cues, or some combination of the two. Limitations of any one of the Level 1 capabilities will limit dexterity unless some means of compensation is achieved, such as using visual information in the absence of tactile information, as is often the case when training for EVA. Three dexterity parameters were of interest in this study:

Table 1-1 Basic Hand Capabilities & Related Parameters

Level	Capability Domain	Parameter
1	Range of Motion	• Thumb Movement • Finger Movement • Wrist Movement
	Strength	• Force (Pinch & Grip) • Torque (Pinch & Grip)
	Tactile Perception	• Continous Sensitivity/Resolution • Objects Characteristics Perception • Tactile Feedback
2	Dexterity	• Precise Positioning • Two Object Manipulation • Flexible Object 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

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single object positioning dexterity, two object manipulation, and flexible object manipulation.

Fatigue, like dexterity, is a complex integrated phenomenon. At least three dimensions of fatigue have been identified: physiological, subjective/motivational, and performance decay(3). While the latter may be a function of physiological and subjective components, decay in performance over time is a commonly used indicator of fatigue. The measurement of fatigue generally involves the assessment of one or all of these dimensions over time. This was the approach of the present study.

The third Level 2 category is comfort. Like fatigue, it is based upon physiological and subjective dimensions. Unlike the other capability areas, comfort is not actually a hand capability area. It is more properly thought of as a set of parameters which address the hand-environment and hand-task interactions. For example, the hand may feel uncomfortable because a glove causes the hand to become hot, because it restricts movement, or because the hand movements required for a particular task were awkward and the hand became very fatigued.

In the present study, the central focus of comfort issues is the hand/glove interaction which is based upon three parameters: glove characteristics such as tenacity, suppleness, and protectiveness(4); glove-hand interaction such as fit, forces (pressure points), and friction between glove and hands; and the immediate environment created by the glove in terms of hand temperature and humidity/wetness.

With respect to glove characteristics, tenacity refers to a glove's resistance to sliding over a grasped surface hence it is related to the coefficient of friction between glove and object. Suppleness refers to the ease with which the fingers can assume desired positions. Protectiveness refers to a gloves ability to protect the hand from injury. Bradley(5) found that these glove characteristics were related to gloved operation of various types of controls.

A third level of hand capability represents the use of the hand in the performance of a "real-world" or integrated task such as assembling a truss strut to a node. Performance of this level of activity is guided not only by the integration of all Level 1 and Level 2 hand capabilities but the integration of the hand with the actions of the rest of the body and other factors as well, such as training. Tasks such as truss assembly and ORU changeout are intuitively appealing because of their relevance and similarly real-world activities. They have several drawbacks, however, when used to assess hand/glove capabilities. First, they are very complicated and generally involve other parts of the body and are heavily dependent on skill and training factors. As such, isolation of the contribution of hand/glove to performance is difficult. Second, measures of performance for real-world tasks tend to be very global and as such are not diagnostic. That is, if performance is bad it is difficult to isolate the specific cause of difficulty, hence the glove designer or researcher is given little direction or insight into how to improve the situation.

In order to understand real-world tasks, it is better to reduce them into the more elementary or primitive capabilities that make them up. The focus of this study was Level 1 and 2 capabilities. Once methods to assess these levels are developed, the relationships between Levels 1 and 2 and the performance of real-world tasks can be established.

1.2 VARIABLES INFLUENCING HAND FUNCTIONING

Many different factors affect the basic hand capabilities. The major factors that have been identified in the literature are listed in Table 1-2. They have been divided into five categories: subject characteristics, glove characteristics, hand-object relationships, environment characteristics, and work characteristics. Some of the important factors within each category have been listed as well.

In the study to be described in this report several of these factors were investigated for their effects on hand capability performance. Specifically, glove characteristics, hand anthropometry, and hand objects relationships were analyzed for their effects on Level 1 and Level 2 hand capabilities, i.e., range of motion, strength, tactile perception, dexterity, fatigue, and comfort.

Table 1-2 Factors Influencing Basic Hand Capabilities

Category	Parameter
Subject Characteristics	• Anthropometry • Sex • Disease/Injury • Training • Age
Glove Characteristics	• Materials & Construction • Pressure Differential • Fit (Interaction with Hand)
Hand Object Relationship	• Object Size • Object Shape • Coefficient of Friction (Between Hand & Object)
Environment Characteristics	• Temperature • Humidity • Vibration
Work Characteristics	• Schedule • Duration

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2 - REVIEW OF PRIOR RESEARCH & MISSION DATA RELATING TO EVA GLOVED HAND PERFORMANCE

This section presents a review of prior work on the effects of EVA gloves and related factors on human hand capabilities. The information for this section was obtained from several sources including astronaut comments, NASA memoranda, technical reports and published literature. An exhaustive literature search was conducted using both computer based search procedures, manually tracking down articles in appropriate conference proceedings and similar publications (most of which do not get picked up in computer databases), and discussing current work with experts in the fields of EVA technology and human hand capabilities. See Appendix A.

The information obtained through these procedures provided a firm basis to develop test methods and design test equipment to evaluate EVA gloved hand capabilities. The presentation of this information is contained in two sections of the report. Section 2 contains data related specifically to the effects of EVA and pressure gloves on hand capabilities. The second discussion is contained in Subsection 4.3 which describes the development of test procedures. The information in that section is more general in that it relates to general human hand performance assessment. We felt it was appropriate to that section because it relates to methods and problems specifically directed to test and protocol design.

The discussion of the effects of EVA gloves on hand capabilities presented in this section is divided into two subsections. The first addresses findings from task analyses and published reports based upon actual EVA missions. The second subsection deals with ground-based laboratory testing of EVA and pressure gloves.

2.1 EVA MISSION EXPERIENCE

In a study such as this, it seemed inherent that a thorough review of actual EVA mission experience would yield valuable insights into hand/glove functions, requirements and limitations. Thus, we screened a large number of EVA mission reports and various other EVA studies and video material. In particular, seven STS missions were analyzed in some detail (STS-6, 41-B, 41-C, 41-G, 51-A, 51-I and 61-B). This effort did increase our understanding of EVA hand/glove factors, but we also came to realize that the applicability of the findings in terms of the specific purposes of this study was limited for several reasons.

First, the mission reports, videos, and studies do not emphasize the ergonomic (physiological work load and work capacity) aspects of EVA. Only one study, performed by Lacey (ILC) in 1986(6), actually addresses hand/arm work in a quantitative manner; and the focus of that study is on glove requirements to tolerate the number of cyclic motions (e.g., finger and wrist flexes, wrist rotations, etc) that are expected in various EVA tasks. These tasks are summarized in Table 2-1. Lacey quantified the frequency of occurrence of various hand motions from mission video tapes. He identified eight generic task categories and four categories of hand activities, three of which involved the wrist. In addition, he observed a number of what were referred to as anomalous hand motions (outside the "Glove Cert Cycle Review Study[6]). Some of these "anamalous" motions were quite frequent and these are shown in Fig. 2-1. However, this and similar studies have not attempted to relate these motions to actual performance of individual tasks. Nor have they included much information on the force requirements for tasks or the fatigue and tactility components of task analysis. None of the studies provided quantitative EVA physiological work measurements.

Second, and perhaps even more important in terms of applicability, the data obtained from actual missions is overwhelmingly influenced by the capabilities and limitations of existing equipment. Indeed, EVA mission planning involves an extensive effort, including high fidelity WETF simulation, to "tailor" individual tasks and total workload so as to accommodate the constraints and shortcomings of the suits, gloves, restraint aids, etc. Furthermore, in the course of training, EVA crew members adopt a variety of unusual techniques (e.g., "holding" articles by "jamming" them between the rigid fingers of the pressure glove, or moving the entire upper body to apply force through the rigid arm of the suit rather than bend the arm, etc) to compensate for undesirable physiological characteristics of the suit and gloves. As a result, observations of task performance on prior EVA missions do not yield unbiased measurements of the ergonomic features of suits or gloves. Even worse, they do not illustrate the techniques, procedures, and capabilities that are

Table 2-1 EVA Task Cycle Rates

Task Category		Avg Cycles per Hr			
		Finger Flex/Ex	Wrist Flex/Ex	Wrist Ad/Ab	Wrist Rotation
Airlock	Rate	287	11	29	39
	% DLC		13	15	0
Tool Stowage (CBSA, SESA, etc)		332	21	72	51
			6	14	4
Translation		368	24	55	25
			22	16	0
MMU		143	17	57	46
			5	13	11
EVA Objectives		266	121	187	301
			0	4	1
MFR Stow/Destow		369	33	28	9
			0	4	0
Contingency		181	14	72	20
			20	14	9
Miscellaneous		134	19	34	21
			0	10	6

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Role of EVA Hand Actions Identified As A Function Of Task
(Figure from Lacey, 1984)

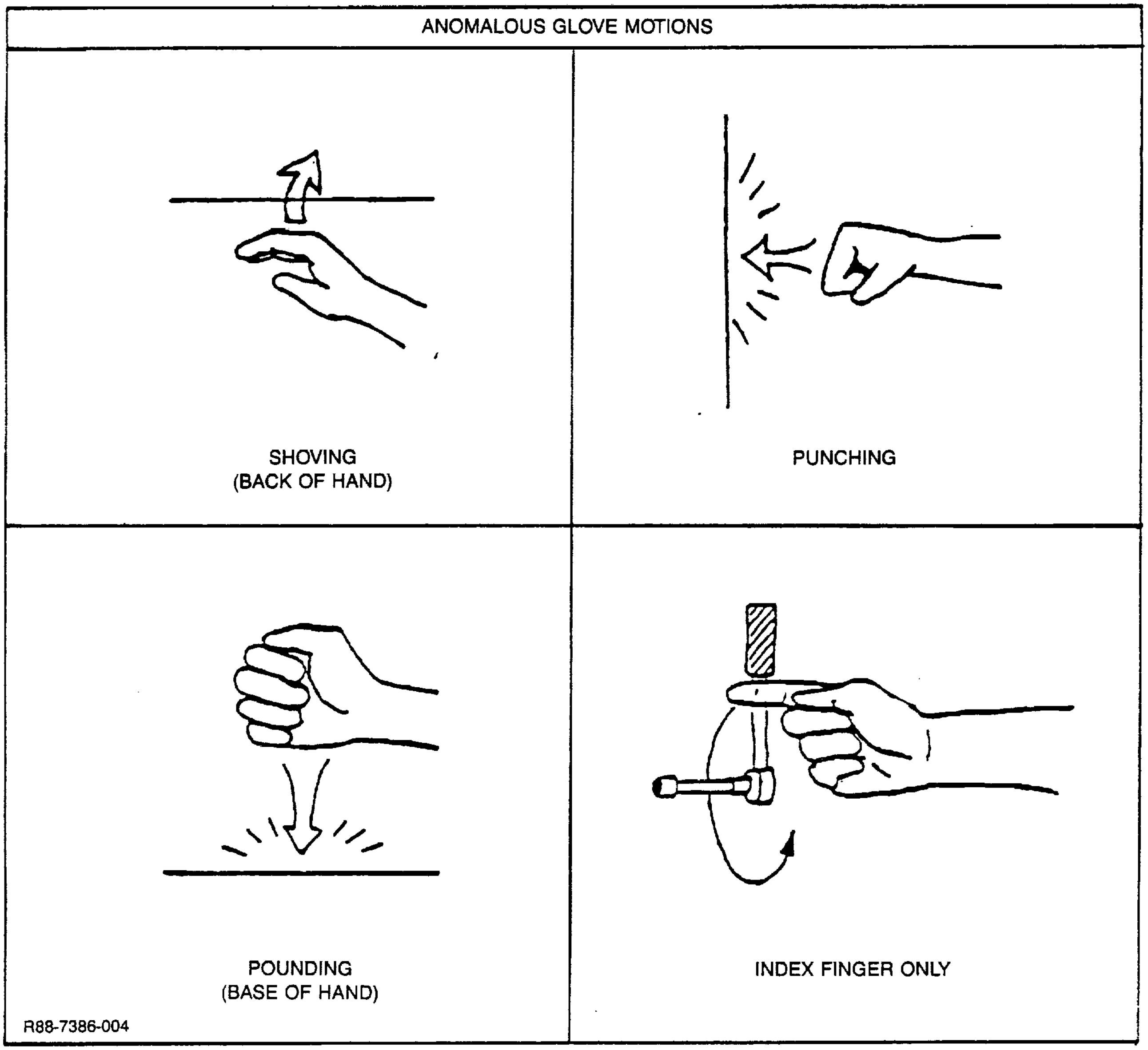

Fig. 2-1 Anomalous Glove Motions (Sheet 1 of 2)
(Figure from Lacey, 1984-Figures 9 & 10)

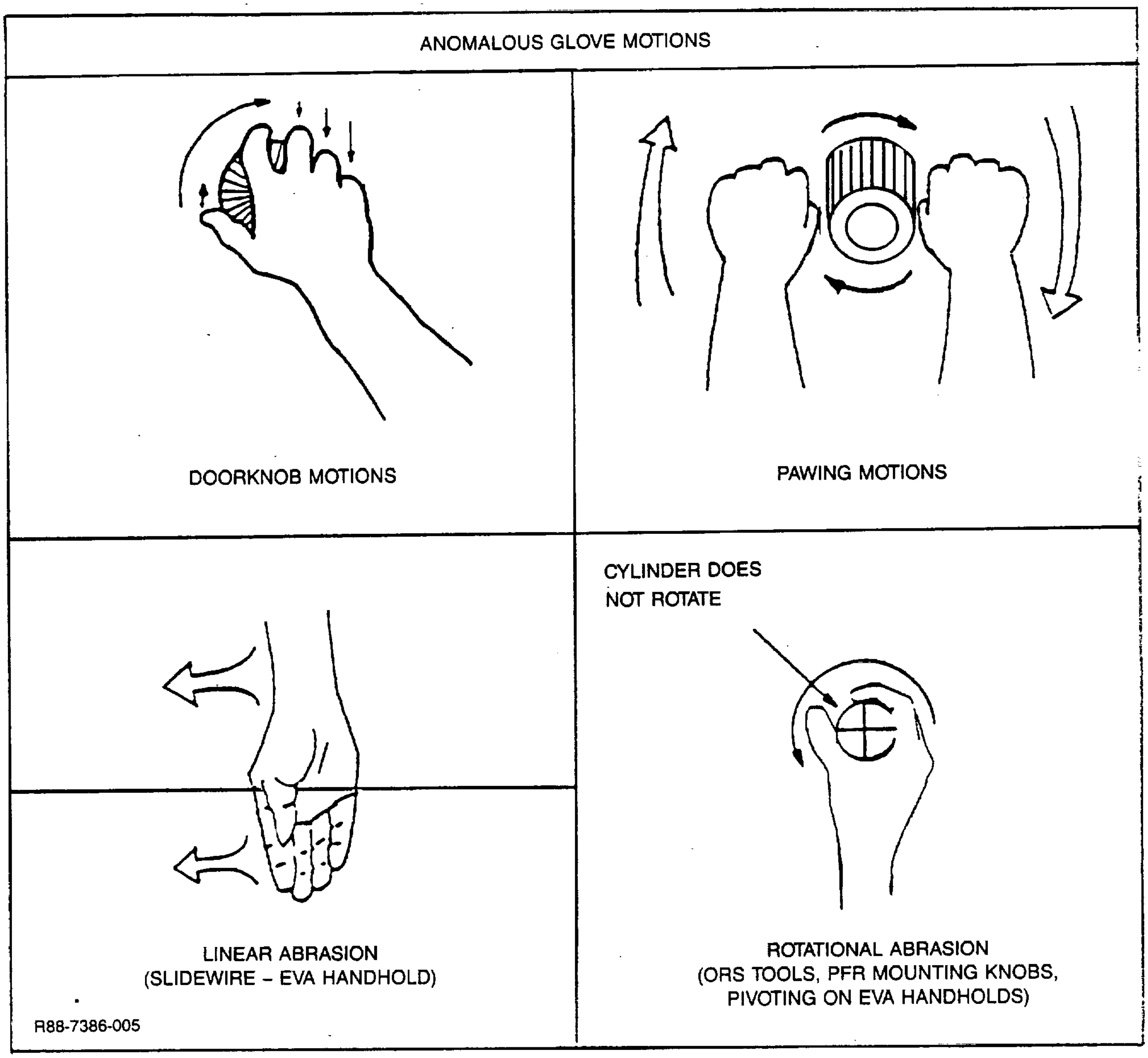

Fig. 2-1 Anomalous Glove Motions (Sheet 2 of 2)
(Figure from Lacey, 1984-Figures 9 & 10)

truly desirable or needed for future missions, but rather the current limited work capacity and methodology that are induced by today's equipment.

Our discussions with crew members and mission planners made it very clear that they think the design requirements for future equipment should not be based upon current practice or capability. The consensus seemed to be that the variety and uncertainty of possible future EVA tasks mandates the development of a comprehensive, flexible, capability that equals bare-hand, shirt-sleeve work capacity as nearly as possible. Therefore, our approach to developing a glove test protocol has been based more on general considerations of physiological hand function than on specific EVA task analysis. However, our review of actual EVA experience did yield some information on tasks and glove features which we feel is applicable.

With regard to hand/glove tasks, there are nine components that occur with increased frequency and in a variety of EVA mission activities and can account for a majority of hand functional activity and requirements. These are:

- 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.

Accordingly, we structured our test protocol to assess the underlying physiological capabilities that are associated with these components. (We did not, however, include these specific tasks in our test protocol because they are not sufficiently generalizable to serve as universal measures of hand/glove performance).

We also identified two glove features that appear to be common to most, if not all, crew critiques of EVA gloves.

- There is a need to improve the overall comfort of EVA gloves. In addition to numerous comments about thermal humidity extremes inside the gloves, there are also consistent reports of pinching, abrasion, numbness and even pain, including loss of fingernails on a few occasions

- The importance of hand/glove fit is consistently emphasized. Any "looseness of fit" even as little as 1/8" between hand fingertips and glove fingertips, results in significant degradation of dexterity and tactility and can impair strength and/or endurance. Conversely, any binding or pressure between hand and glove is likely to produce disproportionate discomfort. In short, exactness of fit is imperative for both performance and comfort.

Furthermore we identified several factors that are related to a specific category of hand capability (e.g., range of motion, strength, etc). These findings are discussed below by category.

Range of Motion:

Sufficient finger range of motion (ROM) is a universal requirement for these tasks to allow the crewman to move the fingers in position for a stable grasp of the object. The ROM required is directly related to the size of the object being handled. Because of the restriction on finger ROM, a thumb and palm grasp or a thumb and index finger grasp is frequently used.

Strength:

Cylindrical grip force is an almost universal requirement, although data to quantify this for various tasks is sparse. Hand (or forearm) suppination/pronation motion (and in many cases torque exertion) is required for most of these task components while hand abduction/adduction is required for a smaller number of tasks. Finger pinch, whether pulp or lateral, is less frequently required, primarily for smaller objects such as pins, switches, screws, or string.

Fatigue:

Astronauts have repeatedly mentioned hand fatigue as the limiting factor in EVA productivity. After STS-61B, it was noted that after about four hours one crewmember experienced hand fatigue to the point that he felt he would have had extreme difficulty in a rescue situation where he was required to take care of the other EVA crewmember. During a ratchet operation on STS-6, an astronaut found it necessary to pause frequently to rest the hand and arm even though actual force required by the device was less than 25 lbf and the handle was designed to accommodate a full, natural cylindrical grasp.

Comfort/Physiological Trauma:

Several of the STS EVA crewmembers have experienced minor physiological damage from gloves including parastesia dead spots, i.e., loss of feeling in fingers and/or thumb, usually temporary, loss of nails, abrasions, bruises, etc. Almost all EVA crewmembers (STS, Apollo, Skylab, etc) have reported discomfort in various degrees including thermal extremes (i.e., from chill and numbness to hot and sweaty wetness in the gloves) "hot spots" (i.e., localized points of extreme pressure) and "rubbing" (i.e., areas where the glove moves relative to the hand causing abrasion).

Dexterity & Tactile Perception:

The STS-61A astronauts observed that it was difficult to grasp cylindrical objects smaller than 3/4" or larger than 2" in diameter. Several STS crew members have noted that as little as 1/4" of excess length in the glove fingers significantly reduces ability to "feel" small objects or precisely manipulate items (e.g., threading a bolt into a nut, untangling a jammed pulley, etc). A Skylab crew member noted that his "job was made harder because the left thumb was too long." An Apollo 17 astronaut noted that a tight form fit was the "best thing (e.g., decision)" he ever made. A 1968 NASA memorandum emphasized that gloves must be short enough to permit crewmen to keep their fingertips in the glove tips. A 1975 NASA memorandum states that "finger tactility" was the highest priority improvement needed. At a recent workshop at JSC, an astronaut office spokesman estimated that, by comparison with bare-hand performance, there is a 20% loss of dexterity for objects greater than one inch in the "dimension of importance" and a dexterity loss of 50% for objects less than one inch, and almost no capability to feel or manipulate "millimeter-sized" objects.

2.2 LABORATORY RESEARCH FINDINGS

To understand the problems associated with EVA gloves, it is important to review the literature not only on EVA gloves but also on factors that affect human hand performance in general. Such a review was undertaken with a special emphasis on studies that evaluated the effect of gloves on performance. In this section only the results of EVA and pressure gloves will be presented. However, Appendix A contains the results of the analysis for the studies determined to be the most significant. Appendix A was set up to provide quick review of the studies by giving a summary of the research in tabular form providing the following:

- Authors and publication date
- Type of glove evaluated
- Method of study
- Independent variables
- Dependent variables
- Types of tests utilized
- Study sample size
- Types of statistics used
- Results summary.

Wherever possible, the results were "normalized" by converting data to reflect the percentage of change from barehand performance. Thus the magnitude of the effects can be compared across the studies. Despite the significance of the EVA glove to manned space operations and the difficulties experienced by astronauts when using gloves, there have been few studies which have attempted to assess the effects of the EVA glove on basic hand capabilities. Table 2-2 lists the studies which assessed the impact of EVA gloves on hand capabilities(7-14). Also listed are several studies of non-EVA pressure gloves, such as high-altitude flying gloves(15-19). While these gloves are not required to meet the stringent demands of EVA gloves, the hand capability issues associated with pressure are generally common to both types of gloves.

There are several factors that limit the establishment of firm conclusions from these investigations. First, many were based on very limited sample sizes, hence the results are confounded with the specific characteristics of the subjects. This makes generalization of results difficult. Second, the studies vary considerably in the types of gloves used and in the secondary factors, such as glove pressure, hand anthropometry, etc. Third, there were significant differences in the hand capabilities evaluated and in the test methods used to evaluate those capabilities. Keeping these caveats in mind, some preliminary trends emerge from the data related to range of motion, strength, fatigue, and tactile perception.

Range of motion of the thumb and fingers has been found to be substantially affected by pressure gloves. Clapp(12) found that both the glove and pressure

Table 2-2 Investigations Of The Effects Of EVA & Pressure Gloves On Hand Capability Functions

Study	Glove	Sample Size	Method	ROM	STR	FAT	TAC	DEX	COM
Pantaleano, 1987	EVA	2	FS			•	•	•	
Farquhar, 1986	EVA	1	FS			•			•
Roesch, 1986	EVA	16	GB		•	•			
Durgin, 1985	EVA	2	GB		•				•
ILC, 1985	EVA	2	FS			•	•		
Clapp, 1984	EVA	1	GB			•	•	•	
Tickner, 1975	EVA	6	GB		•				•
Walk, 1964	EVA	17	FS		•			•	
Peacock, 1985	Press	4	GB		•	•		•	
Garrett, 1971	Press	?	FS		•				
Slowik, 1969	Press	1	GB					•	
Garrett, 1968	Press	27	FS			•			
Siegal, 1968	Press	- -	FS			•		•	

NOTE: GLOVE = EVA = Extravehicular activiries glove
PRESS = Non EVA pressure glove
METH = Method/FS = Full suit, GB - Glove box
ROM = Range of motion
STR = Strength

FAT = Fatigue
TAC = Tactile perception
DEX = Dexterity
COM = Comfort

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contribute to finger and wrist restriction. The A7L-B glove at 0 psid restricted finger movement to approximately 63% of bare hand range and at 3.5 psid the fingers were restricted to approximately 31% of full range. The wrist was restricted to 52% of bare hand range with the gloves at either pressure. Durgin(10) tested an experimental EVA glove design. The average finger range was restricted to 87% of bare hand capability and 74% when pressurized to 8 psid. The greatest impact, however, was found in thumb movement restriction which was 95% of full range in unpressurized gloves but only 19% under pressure. As a result, spherical grasp modes were extremely difficult to achieve and cylindrical grasps were moderately difficult.

Garrett(16,18) evaluated ROM restriction imposed by A/P 225-2 high altitude pressure suit gloves. As with EVA gloves, independent contributions of glove and pressure were observed. Suppination and pronation were restrained to an average of 83% bare hand capability at 0 psid and 51% at 3.4 psid. These values are consistent with wrist movement restrictions associated with the A7L-B EVA glove(12).

In summary, these studies suggest that:

- EVA gloves restrict the hand's range of motion
- Pressure has a great effect on range of motion restriction and its contribution may be greater than that of the gloves themselves
- The thumb is the hand element most affected by the pressure glove making grasping difficult.

Strength has also been found to be affected by pressure gloves. Roesch(9) evaluated the affect of the Series 1000 and 3000 Shuttle EVA gloves on maximum hand grip strength. Maximum grip strength was reduced to 65% of bare hand strength when operating at 0.5 psid and to 58% at 4.3 psid. Hand and elbow position variations were found to significantly affect strength measurements. Garrett(16) found a similar decrement in strength with increasing pressure for high-altitude gloves. Grip strength was reduced from 75% of barehand at 0 psid to 62% of barehand at 3.5 psid. Torque production was not as much affected by gloves as force production. Suppination torque was 92% of barehand at 0 psid and 79% at 3.5 psid while pronation torque (counter clockwise knob turn) was 104% of barehand at 0 psid and 98% at 3.5 psid. The finding that gloves have much less effect on the hands ability to generate torque than force has been documented elsewhere in the literature (Bensel[20]).

Farquhar(8) studied the effect of several EVA gloves (including the ILC Shuttle 1000, 3000, 4000, and Phase II advanced development glove, and David Clarke Phase I, Phase II, Phase III advanced development glove) on the hand strength of one subject. Strength was assessed along two dimensions: (1) type of hand action and (2) static and dynamic measurement. In addition, the gloves were tested at 4 and 8 psid. The results are summarized in Table 2-3. Several trends appeared in these data. First, strength values were generally degraded from bare hand capabilities. Second, the extent of degradation varied considerably across types of hand actions. Third, dynamic strength values were lower than static values. Fourth, the increase in pressure from 4 to 8 psid caused only a slight degradation in performance in most hand action categories.

Table 2-3 Percent of Barehand Strength as a Function of Hand Action, Type of Strength Measurement & Pressure, psid

Hand Action	Strength Measurement			
	Static		Dynamic	
	4 psid	8 psid	4 psid	8 psid
Suppination/Pronation	62-73	51-74	62-129	53-83
Grip Strength	66-84	62-97	38-78	28-56
Pinch Grasp	69-92	68-87	59-93	39-50
Cylindrical Grasp	42-55	35-47	12-31	10-23
Hydrazine Transfer Tool	108-131	106-127	53-125	44-76

Note: 1. Numbers represent the range of % of barehand capability over all gloves tested.
2. Data are from Farguhar, 1986.

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Clapp(12) examined the change in maximum strength as a function of the number of repetitions a ball grip was squeezed. A bare hand function was compared to functions generated with an AL7 EVA glove and an experimental skinsuit glove. Very little difference between the three conditions was noted on the first few squeezes. The curves separated considerably after 20 repetitions and the separation continuously increased until the 60th trial. At that point, the bare hand value was approximately 70% of its initial trial, the skinsuit was approximately 60% of the initial bare hand trial, and the AL7 glove was at about 20% of the initial bare hand trial. If the change in strength over trials can be assumed to be related to fatigue, then it can be concluded that the EVA glove was associated with greater fatigue than was experienced in the bare hand condition.

In summary, these studies suggest that:

- Gloves generally reduce strength when compared to bare hand performance
- Pressure has a further detrimental affect on strength above that of the gloves alone
- The effect of EVA gloves may be different for measures of force vs torque
- Measures of dynamic strength are more strongly affected than measures of static strength
- The type of hand position has an effect on strength measures
- Strength reduction (fatigue) rates are greater when wearing EVA gloves than barehand.

Only one study presented data on the effect of the EVA glove on tactility. Clapp(12) asked a subject to recognize patterns formed from raised dots that were either 2 mm or 4 mm high. The task was performed barehanded, with the A7L-B glove and with the experimental skinsuit glove. The subject was instructed to press the finger on the patterns and keep it stationary. The test was performed at 0 and 3.5 psid. There were no pressure effects, however, so only the 0 psid data was presented. When barehanded, the subject was capable of correctly recognizing all patterns at both dot sizes. At 4 mm, the A7L-B glove reduced correct recognition to 75% and 30% at 2 mm. With the skinsuit glove, the subject's performance was 100% and 90% correct at 4 and 2 mm, respectively. These results indicate that the typical EVA glove substantially reduces tactility in the area of pattern detection.

2.3 CONCLUSIONS

The results of these investigations in conjunction with the astronaut comments support the fact that the EVA glove has significant impact on hand capabilities such as range of motion, strength, fatigue, and tactility. While some tentative trends reflecting the extent to which hand capabilities are affected can be identified, there is a need for a more quantitative , standardized, and systematic hand testing methodology.

3 - PHASE II TEST PROGRAM OBJECTIVES

3.1 PRINCIPAL STUDY OBJECTIVES

As indicated in the introduction, there were two main goals of this study. Associated with these goals were a set of test objectives.

The first goal was to develop and evaluate a set of test methods designed to assess basic hand capabilities for use by glove designers, engineers, and researchers in the assessment of the human factors parameters related to glove design. The test objective related to this goal is to derive a set of tests that are objective, standardized, provide quantitative data, and are sensitive with a range from bare hand to the pressurized gloved hand.

The second goal of the program was to develop a database of bare hand and gloved hand capabilities for a representative EVA glove. Several test objectives were defined in terms of (and within the limitations of) the variables and experimental design of the study. (The details of the experimental design are described more fully in Section 4 - Experimental Methodology.)

Three of the objectives apply to all tests, without regard for the specific hand capability domain. These three objectives are:

1. To evaluate the relative effects of the EVA glove on basic hand capabilities.
2. To evaluate the relative effects of glove differential pressure on basic hand capabilities.
3. To evaluate the relative effect of hand size on basic hand capabilities.

These objectives are referred to as the Principal Study Objectives.

3.2 TEST OBJECTIVES RELATED TO SPECIFIC HAND CAPABILITY DOMAINS

In addition to the overall test objectives indicated above, several subobjectives were identified for each specific hand capability performance domain investigated. These capability area specific objectives are listed below and are discussed more fully in the detailed test development section - Subsection 4.3.

Range of Motion:

To evaluate the effect of various hand positions (such as metacarpophalangeal flexion vs extension) on range of motion data.

Strength:

To evaluate the effect of type of hand grip (such as pulp pinch vs cylinder grip) on strength.

Tactile Perception:

To evaluate the effect of point gap width (i.e., gap vs no gap) on subjects perception of two points.

To evaluate the effect of object size and shape on subjects object recognition accuracy and response time.

To identify the effect of type of grip (fingers vs palm), weight (light vs heavy), and handle type (smooth vs coarse) on the grip force with which the subjects hold an object.

Dexterity:

To evaluate the effect of object size on positioning dexterity, two hand object manipulation, and flexible object manipulation.

Fatigue:

To assess the change in physiological, subjective, and performance fatigue over trials (time).

4 - TEST METHODOLOGY

4.1 TEST SUBJECTS

A total of 11 test subjects participated in this study. The selection characteristics of this sample included:

- Ten men and one woman
- To insure a range of hand anthropometry, the males were divided into small, medium, and large hand size groups on the basis of hand anthropometry
- Participants were not experts in the use of EVA gloves and most did not have more than four hours of EVA glove usage
- None of the subjects had any physical disabilities that would have impaired their ability to do manual hand tasks.

The original plan was to include 9 men and 9 women in the study. However, EVA gloves were not available for most of the women's sizes except for the largest hand size. We were, therefore, only able to include one woman in the test program. In the analyses to be reported, her test data was not included with the data of the male subjects.

The decision to select subjects with minimal EVA glove experience was based upon the following rationale. In the ideal case, test subjects would differ only in those variables which are under investigation since other variations create error variance in the data. Because the ideal case cannot be achieved, it is important to identify which of these secondary characteristics are likely to be highly correlated with the dependent variables under investigation and then to control their effects. One method of obtaining this control is to hold the secondary variables as constant as possible. With respect to this study, experience with EVA gloves was expected to affect performance. Since it was deemed unlikely that we could obtain all subjects with EVA glove experience and the desired distribution of hand anthropometry, the decision was made to select subjects who had a minimum of experience, thereby eliminating the effect of this factor. In addition, inexperienced subjects did not come to the test with a knowledge acquired through extensive training of how to overcome some of the hand limitations imposed by the gloves.

Participants in these tests were volunteers and ILC Dover employees. Each completed an informed consent form prior to participating in the study. This form is contained in Appendix B. A description of these subjects is provided in Table 4-1 which is further discussed in Subsection 4.2-1.

Table 4-1 Subject Description

Hand Sizes					
Subject Code	Hand Dimensions Area (in.^{2})	Length	Circumference	Hand Class	Subject Age
211	60	7-1/2	8	SMALL	23
212	60.84	7-3/8	8-1/4	SMALL	31
213	60.84	7-3/8	8-1/4	SMALL	31
222	61.63	7-3/4	8-1/2	MEDIUM	35
223	61.36	7-7/16	8-1/4	MEDIUM	55
224	66.84	7-3/4	8-5/8	MEDIUM	31
231	72.11	8-1/8	8-7/8	LARGE	39
232	74.25	8-1/4	9	LARGE	36
233	70.875	7-7/8	9	LARGE	31
234	75.16	8-1/8	9-1/4	LARGE	33

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4.2 EXPERIMENTAL DESIGN

The experimental design describes the general plan or organization of the study. It includes: (1) the independent variables (IV), the factors whose effects on hand capabilities were investigated; (2) the dependent variables (DV), the basic hand capabilities measured; and (3) the secondary variables, to be controlled in order to minimize their influence on the results. In this section the variables will be defined. The discussion of controls is distributed across the dependent variables section since controls tend to be specific to particular capability areas.

4.2.1 Independent Variables

The effects of three principal independent variables (IV) on hand capabilities were investigated.

- Gloved/Bare Hand
- Pressure Differential
- Hand Size.

The first two IVs were related to the effects of the EVA glove on hand functioning. The effects of the glove can be broken into two components, the glove itself and its operating pressure. The study evaluated the relative contributions of both components. The gloved/bare hand variable had two levels. All tests were conducted with the bare hand and with the 1000 Series Shuttle Glove. While the 1000 Series glove is not the current Shuttle glove, it is representative of EVA gloves. Since the purpose of this effort is not to test a specific configuration EVA gloves per se, but rather to develop test methods with which to assess the effects of pressure gloves on hand capabilities, the 1000 Series glove was determined to be suitable.

The second IV is pressure differential. For most tests two levels of this variable were evaluated - 0 psid and 4.3 psid (the normal operating pressure of the 1000 Series glove). Tests of the glove at these pressure differentials permit a determination of the independent contributions of the glove (0 psid performance - bare hand performance) and the pressure (4.3 psid performance - 0 psid hand performance). For range of motion tests, an intermediate pressure of 2.3 psid was also tested because previous research has suggested that range of motion is particularly sensitive to pressure effects.

In summary, the glove/barehand and pressure differential variables had two and three levels. An orthogonal combination of these two variables would produce six test conditions. However, since the bare hand cannot be tested at 2.3 or 4.3 psid, only four test conditions were investigated.

- Bare hand at 0 psid
- Gloved hand at 0 psid
- Gloved hand at 2.3 psid (range of motion tests only)
- Gloved hand at 4.3 psid. This variable was referred to as "Glove Condition." Each subject participated in all four levels.

The last IV, hand size, was related to subject characteristics. The EMU system is designed to accommodate men and women with a wide range of body sizes, therefore, it is important to determine if the effect of EVA gloves on hand capabilities varies across hand sizes.

The hand size categories used in this study were determined as follows. Hand sizes were defined on the basis of hand length and hand circumference parameters. These two parameters were determined to be the most salient dimensions defining hand size in recent USAF research(21). To ensure proper variation in hand sizes the following procedure was used to define the hand size intervals which will guide subject selection. USAF hand anthropometry data reported by Garret(22,23) were used to obtain the mean and standard deviation of male and female hand length and circumference. These data were based upon 148 and 211 subjects respectively and compared very well with earlier USAF studies based upon approximately 2,000 women and 4,000 men. The Garret data were used because they were more recent. The data are summarized in Table 4-2.

From these data the range of hand lengths and circumferences including 95% of the population was determined by a normal curve approximation. This was done separately for men and women. The resulting 95% intervals were rounded off and hand length was plotted against circumference (see Fig. 4-1). Each range was then

Table 4-2 Garrett (1970 a & b) Hand Anthropometry Data In.

Parameter	Statistic	Sex Of Subject	
		Male	Female
Hand Length	M	7.76	7.06
	SD	0.37	0.34
	N	148	211
Hand Circumference	M	8.50	7.37
	SD	0.35	0.33
	N	148	211

Note: M=Mean SD=Standard Deviation N=Number

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divided into thirds representing small, medium, and large intervals for each dimension. The three hand size categories for each sex were defined as the area of intersection between small, medium, and large hand length and hand circumference. For example, a small sized hand was defined as the area of intersection between the interval representing small hand length and small hand circumference.

Figure 4-1 illustrates the areas defining small, medium, and large hand sizes for men and women. These categories were used to guide subject selection rather than being considered as absolute criteria. The probability of a person falling within the medium category is approximately 0.38 while the probability of falling within either the small or large categories is approximately 0.13. Hence, it was difficult to find people exactly fitting small and large criteria. Where difficulty was encountered subject selection was based upon minimizing the deviations of the subjects selected and the "regression line" in Fig. 4-1. By definition, hand size was varied between subjects (i.e., each subject will represent one hand size condition).

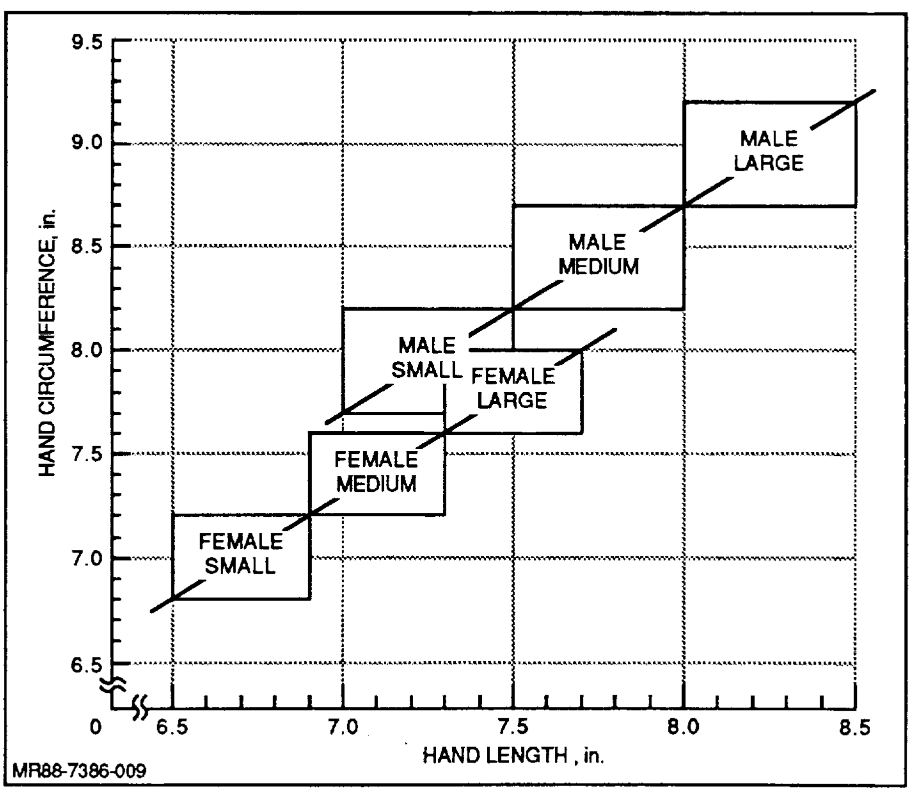

Fig. 4-1 Hand Size Categories (Estimated N = 3 in Each Cell)

In summary, the overall design of the test included one within-subjects factor (glove condition) and one between-subjects factor (hand size). The principal experimental design, therefore, is a split-plot factorial design (24).

In addition to the principal study design, several independent variables were defined which were unique to each test. These independent variables are identified in Table 4-3. All are varied within subjects. A discussion of each of these variables is presented in Subsection 4.3. The table represents an overview of the tests conducted in each of the six capability areas and includes the factors manipulated in the test (the independent variables) and the measurements obtained (dependent variables). Since the principal experimental design is a split-plot factorial and, therefore, includes both between- and within-subject variables, the addition of test specific within-subjects variables does not alter the basic design.

4.2.2 Dependent Variables

To conduct a thorough evaluation of basic hand capabilities, it was necessary to assess all six categories: range of motion, strength, tactile perception, dexterity, fatigue, and comfort. The specific dependent variables (measurements) associated with each capability domain were listed in Table 4-3. The measurements are grouped by the test methods utilized to obtain the data. These methods are discussed in detail in the next Subsection 4.3 - Basic Capability Tests and Procedures.

Several criteria were used to guide the development of measurement methods in this test program. These criteria are important characteristics for any measuring instrument or method:

- Validity - The test is a true indicator of the hand capability it represents
- Objectivity - The test is minimally influenced by the judgment of the person conducting the test
- Quantitative - The test yields numerical results/data
- Standardized - The test procedures are structured such that every subject takes the test in the same way and under the same conditions
- Reliability - The test yields consistent measurements under the same conditions
- Uniqueness - The test provides information which is minimally redundant with other tests

Table 4-3 Overview of Test Specific Independent & Dependent Variables

Capability Domain	Test	Independent Variables	Measurement Dependent Variable
Range Of Motion	Photometrics	• Type Of Motion - Thumb Opposition - Mcp Group Flexion - Mcp Group Extension - Mcp1 Flexion - Mcp1 Extension - Mcp2 Flexion - Pip1 Flexion - Pip1 Extension - Pip2 Flexion - Wrist Adduction - Wrist Abduction - Wrist Pronation - Wrist Suppination - Wrist Flexion - Wrist Extension	• Degrees
Strength	Bte	• Type Of Grip - Pulp Pinch Squeeze - Key Pinch Squeeze - Cylinder Grip Squeeze - Key Pinch Protonation - Key Pinch Suppination - Cylinder Grip Protonation - Cylinder Grip Suppination - Chuck Pinch Protonation - Chuck Pinch Suppination	• In-lbs • Lbs
Tactile Perception	Two-point Discrimination	• Gap Conditions - Gap - No Gap	• Error Frequency • Gap at Which Subject Perceives Two Points
	Object Identification	• Object Shape - Cube - Sphere - Cylinder • Object Size - Small - Medium - Large	• Percent of Correct Shape & Size Identification • Response Time
	Grip Force Control Perception Test	• Type of Grip - Fingers - Palm • Handle Coefficient of Friction - Smooth - Coarse • Weight - Light - Heavy	• Safety Margin (Holding Grip Force-slip Force)

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Table 4-3 Overview of Test Specific Independent & Dependent Variables

Capability Domain	Test	Independent Variables	Measurement Dependent Variable
Dexterity	Pegboard	• Peg Size - Small - Medium - Large	• Number of Peg Insertions • Number of Pegs Dropped
	Nut & Bolt Assembly	• Nut And Bolt Assembly Size - Small - Medium - Large	• Number of Assembles Completed • Number Dropped
	Knot Tying Test	• Rope Diameter - Small - Large	• Seconds to Complete
Fatigue	Physiological-Muscle Fatigue	• Trial	• Change in Emg Median Frequency Over Trials
	Subjective	• Trial	• Rating Scale During Fatigue Protocol • Ratings After Protocol
	Performance Decline	• Trial	• Trial 1 Work • Average Work Overtrials • Slope of Decay Curve
Comfort	Questionnaire	• Comfort Dimensions - Discomfort - Chafing - Cutting - Pinching - Numbing - Hot - Cold - Wet Feeling - Dry Feeling	• Nine Point General Discomfort Scale • Three-point Rating Scales Identifying Specific Problems

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- Sensitivity - The test can discriminate between the test conditions under investigation
- Efficiency - The test is easy to administer and not complicated, confusing, or unduly frustrating to the test subject.

In addition to these general test evaluation criteria, two additional considerations were made:

- Minimize Learning Effects - Learning effects create noise in the data which make the detection of effects of interest more difficult. An attempt was made to eliminate tests that required more than two or three trials for a subject to approach asymptotic performance.
- Glove Box Compatible - All tests were designed to be accomplished within a glove box. Since the intent of the study is to isolate hand/glove effects, an effort was made to minimize as much as possible the requirement of moving any part of the body other than the hand itself. Hence, the tests were designed to be accomplished with little or no elbow movement.

Evaluations of previous EVA glove testing using full-suit methodology and astronaut comments about the use of EVA gloves revealed that the test participants are able to overcome glove deficiencies using full arm or body movements. Hence, the glove evaluation is confounded by the possibility of such alternative strategies. The glove box provides a high degree of control over variables that impact glove performance. In addition, full pressure suit testing is costly and logistically difficult. A set of test procedures based on glove box methodology provides a simple, cost effective, and more controlled program.

4.3 BASIC CAPABILITY TESTS & TEST PROCEDURES

4.3.1 Test Lab & EVA Gloves

Glove testing was conducted in the Glove Test Laboratory at ILC Dover, Frederica, Delaware.

The test lab was a trailer, 11' x 26', dedicated to the test program. Adequate lighting was provided by large fluorescent ceiling lights and five large windows. The test lab was divided into three sections. On one side of the room, cabinets were installed to provide storage space for the EVA gloves, for glove testing equipment, and the test data. The middle of the test lab was furnished with a desk and several chairs and was used as a waiting area for test subjects, for briefings and debriefings, for questionnaires completion, and subjective evaluations. On the other side of the test lab the ILC glove box along with associated test support equipment were installed.

The glove box used in this study was furnished by NASA, the box was cylindrical in shape, approximately 2 ft in diameter and 4 ft in length with an internal volume of 13 ft^3 (see Fig. 4-2). The cylindrical section was 1/2 in. thick plexiglass. The two reinforced end caps were 1 in. plexiglass. One end cap was installed with an O-ring and quick release clamps and could be removed to provide access to the inside of the glove box. .

About midway along the axis of the glove box were 2 six-in. circular openings in the cylinder wall, placed shoulder width apart, which provided the access and attachment points for the EVA glove and arm assemblies. O-rings provided the seals between the glove box and the arm assemblies at these locations. By means of glove port plugs, the glove box was designed to allow the use of one or both arm assemblies. Other parts of the glove box included a regulator/safety valve, pressure control valve, pressure glove, and a lab facility vacuum pump.

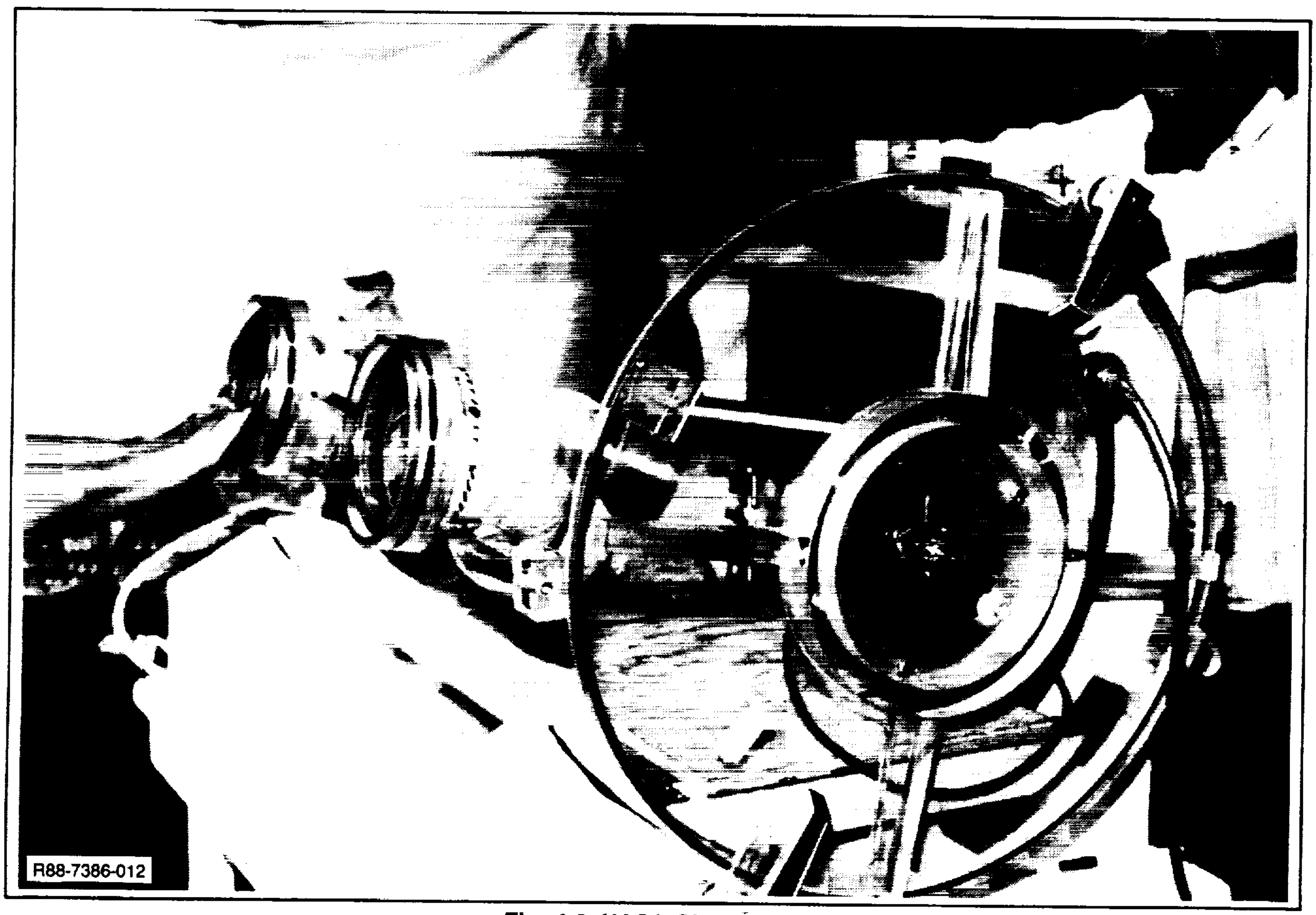

Fig. 4-2 NASA Glove Box

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At one end of the glove box, mounted perpendicular to the end cap, was a Sony Video CamCorder, used to record ROM tasks in the glove box. The glove box was designed to test a variety of EVA gloves. For this study the Series 1000 Shuttle Glove was used (see Fig. 4-3).

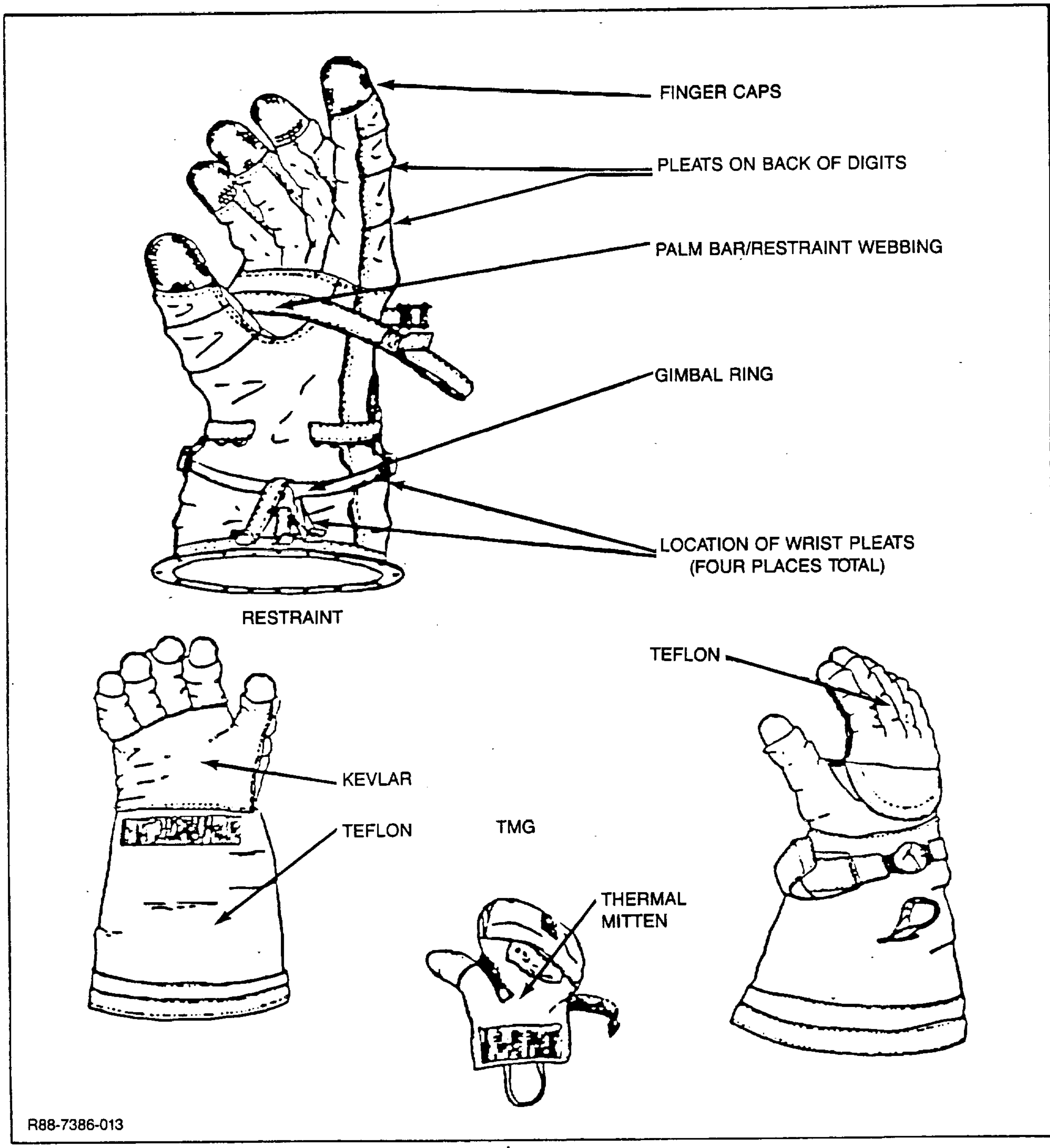

Fig. 4-3 1000 Series Shuttle Glove

4.3.2 General Test Procedures

Test subjects were selected and sized for the 1000 Series glove based upon hand length and circumference. The glove sizes in relationship to these parameters are shown in Fig. 4-4. Since no custom glove fitting was used for this test, the gloves provided by NASA were used to obtain the best possible fit. Test subjects were examined for finger tip and finger crotch fit after donning the glove. These two factors have been identified by ILC as critical to proper glove fit. If the test conductor and subject judged these parameters to be unacceptable, the next size glove was tried and the fit was re-evaluated.

Prior to testing, each test subject was briefed on the purpose of the study and the test methods being used. The subjects were told that the tests were intended to measure the effects of gloves, pressure, and hand size on the general hand capabilities of hand strength, fatigue, tactility, dexterity and range of motion. Following the description of the purpose for testing, the subjects were shown the various equipment intended to measure the hand characteristics under investigation. The test experiments were demonstrated by the test conductors and the test subjects were allowed to become familiar with the glove under pressure by trying the gloves in the glove box.

Included in the briefing procedure was a participant consent form (see Appendix B) which further reiterated the purpose for performing the test and the nature of the tasks involved. Also, test subjects were asked to to complete a background questionnaire (see Appendix B) to determine the general fitness of the subjects arms and hands, the subjects health and whether or not he/she was taking medication, the type and level of normal hand work the subject engaged in, and the subjects experience with EVA gloves.

Tests were sequenced to minimize fatigue effects among individual test subjects and to maximize the efficiency of the test conductors in setting up and conducting the tests. To control for sequence effects such as training, fatigue, and boredom, the order of test conditions were varied across subjects in a Latin Square fashion. For example, subject 1 was tested in the barehand, glove-0 psid, glove-4.3 psid conditions while subject two was tested in a different order. Additionally, to control for sequence effects within individual tests, the order of variables were also varied in a Latin Square fashion. So, for example, if one subject performed the Nut and

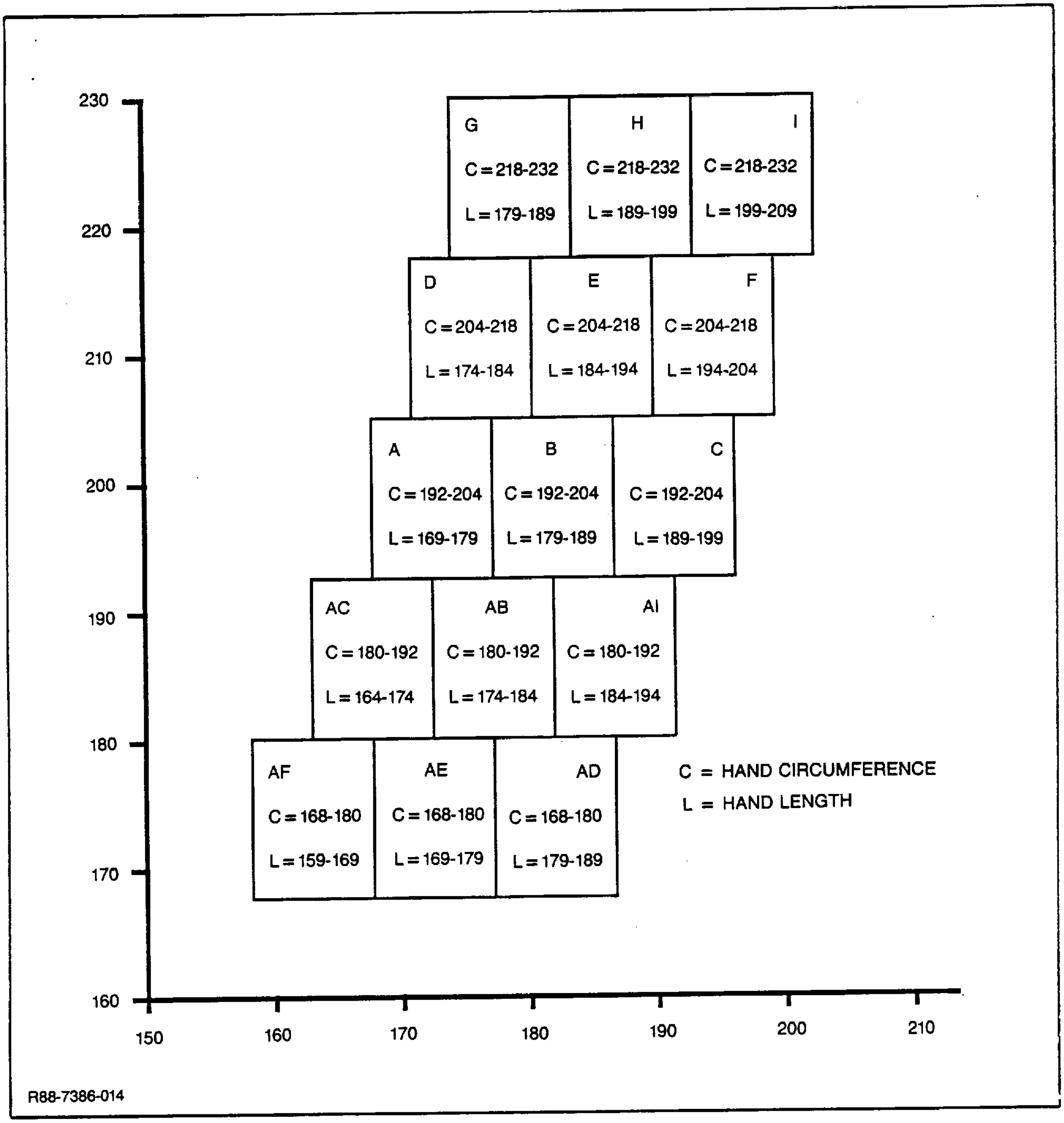

Fig. 4-4 ILC 1000 Series Glove Sizing Schedule

Bolt Assembly Test by assembling bolts in groups of small, medium, and large, the following subject was presented with the bolts in a different order. Testing was conducted in two phases (see Fig. 4-5). During the first phase subjects were tested for hand fatigue with two subjects testing in one test condition, e.g., barehand, or glove, during the morning, and another two subjects testing in the afternoon. All subjects were given at least one day of rest before being tested for

▒ = Days when subject did not test (may exceed one day in duration)		TESTING DAYS 1	2	3	4	5	6	7	8
PHASE 1	• Fatigue Test								
	Bare		▒	•	▒		▒		
	Glove - 0 Psid		▒		▒	•	▒		
	Glove - 4.3 Psid	•	▒		▒		▒		
PHASE 2 ALL CONDITIONS	• Range Of Motion Test		▒		▒		▒	•	
	• Strength Test		▒		▒		▒	•	
	• Two-Point Discrimination Test		▒		▒		▒	•	
	• Pegboard Test		▒		▒		▒	•	
	• Grip/Slip Test		▒		▒		▒		•
	• Object Identification Test		▒		▒		▒		•
	• Knot Tying Test		▒		▒		▒		•
	• Nut & Bolt Test		▒		▒		▒		•

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Fig. 4-5 Test Schedule for a Typical Subject

hand fatigue in a different test condition. Phase two included the remainder of the tests with each subject completing this phase on two separate days by testing for three hours on each day. The test sequence for the first day was as follows:

- Range of Motion Test
- Strength Test
- Two-Point Discrimination Test
- Pegboard Test.

The test sequence for the second day, which may or may not have been the day after the first sequence depending on test subject availability, was:

- Grip/Slip Test
- Object Identification Test
- Knot Tying Test
- Nut and Bolt Test.

4.3.3 Range of Motion

Two types of range of motion (ROM) can be defined: (1) passive, where external torques are applied and the resulting angular displacement is measured, and (2) active, where the subject applies maximum muscular contraction to effect maximum active angular displacement. While tests of passive ROM do provide good quantitative measure by allowing the derivation of torque vs angular displacement functions, there are inherent restrictions that limit the usefulness of the results. The maximum applied torque must be selected arbitrarily and is not assured of correlating to any meaningful number. In addition, the loading patterns may differ, particularly in the case of gloved hands, from active normal loading applied by the subject. Conversely, active ROM measurement supplies a true measure of the subject's maximum ROM capability under controlled test conditions.

Videotape of active ROM movements were used in this study to provide a photometric record for later data analysis. The video camera was aligned parallel to the axis of motion. Anatomical landmarks were located and the angular displacement measured directly from the video frame. In cases where linear measurements were required, these were calibrated against a grid.

There are many joints in the hand that could be the subject of range of motion testing. Many of these are difficult to measure, especially in pressure gloves due to the imprecise anatomical landmarks. A representative set of these parameters were selected which were most closely related to hand function and which could be reliably measured in pressure gloves. These motions are illustrated in Fig. 4-6.

EVA gloves are historically most constraining on metacarpophalangeal (MCP) joint motion and, in fact, essentially force the MCP joints of digits 3-5 to function somewhat as a unit. Thus, the flexion and extension of the fingers as a unit was measured. To delineate the capability of a glove to allow single MCP joint motion, the flexion and extension of the index finger (MCP2) was measured with digits 3-5 held in a neutral position. Glove fingers were assumed to be uniform and the ROM of the proximal interphalangeal joint (PIP) in digit 2 (index finger) was measured. Measurement of the distal interphalangeal (DIP) joint motion of hands in pressure gloves was determined to be impractical.

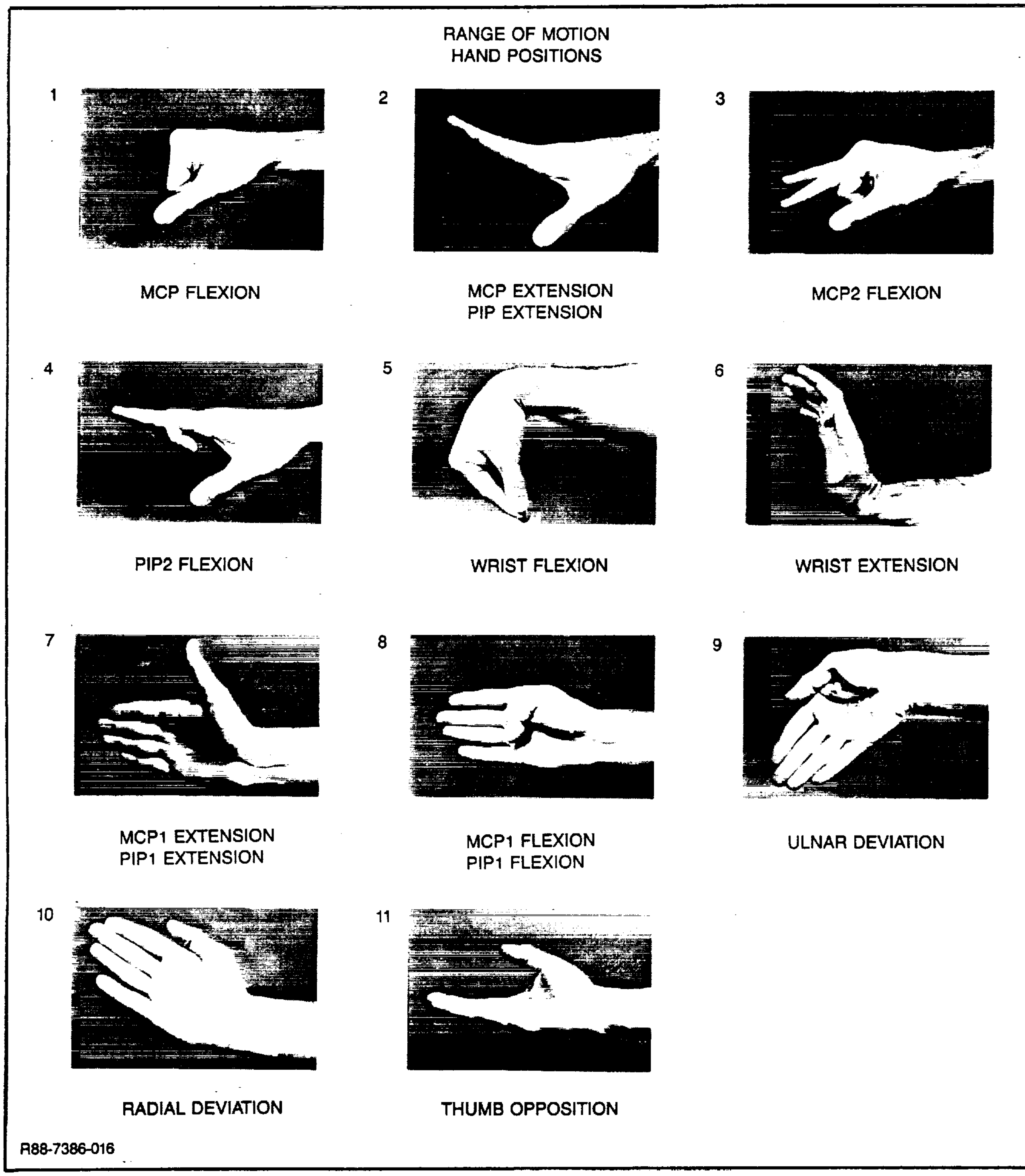

Fig. 4-6 Range of Motion Tests

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The thumb offers a unique challenge in assessing range of motion. Motion of the MCP1 and PIP1 are important and should be measured. However, functionally the thumb works as a unit which includes 3-axis motion at the carpometacarpal (CMC) joint. Angular motion at the CMC joint is impossible to measure without radiography or semi-invasive techniques due to the lack of anatomical landmarks. Thumb opposition, therefore, was measured as the primary parameter of total thumb functions. Thumb opposition is important in determining the functionality of the thumb in gripping objects of almost any size and shape. Opposition required the subject to place the tip of the thumb over the head of the third metacarpal and to maximize the perpendicular distance from the palm to the thumb tip.

Wrist ranges of motion are more difficult to measure reliably due to interfering forearm/elbow effects. However, these are included since wrist motions are a part of EVA glove design, at least within the current EMU configuration. With the wrist in a neutral position, wrist flexion/extension and wrist adduction/abduction was measured. Then hand pronation and suppination were measured by having the subject grip a "D" handle and turn it clockwise and counter clockwise to the maximum extent possible to measure the angular rotation (see Fig. 4-7).

A test stand was developed to provide support for the hand/arm during ROM tests (see Fig. 4-8). A copy of the data form is provided in Appendix B.

4.3.4 Hand Strength Assessment

Strength measures were obtained during a maximum voluntary contraction for each strength test parameter. Since data were obtained for brief contractions, fatigue was minimized.

Three pinch tests were conducted. The first was the pulp pinch which is the maximum force exerted between the palmar surfaces of the tips of the thumb and index finger. This is the typical pinch one would use in picking up a pencil. The second pinch measure was the chuck pinch torque which employs the tips of digits 1, 2 and 3 similar to a mechanical chuck. While this was not substantially different than the pulp pinch, it is more representative of pinch motions during EVA. The third was the key pinch, so named for its most common application. This pinch employs the thumb pulp applied to the medial surface of the DIP joint of the index

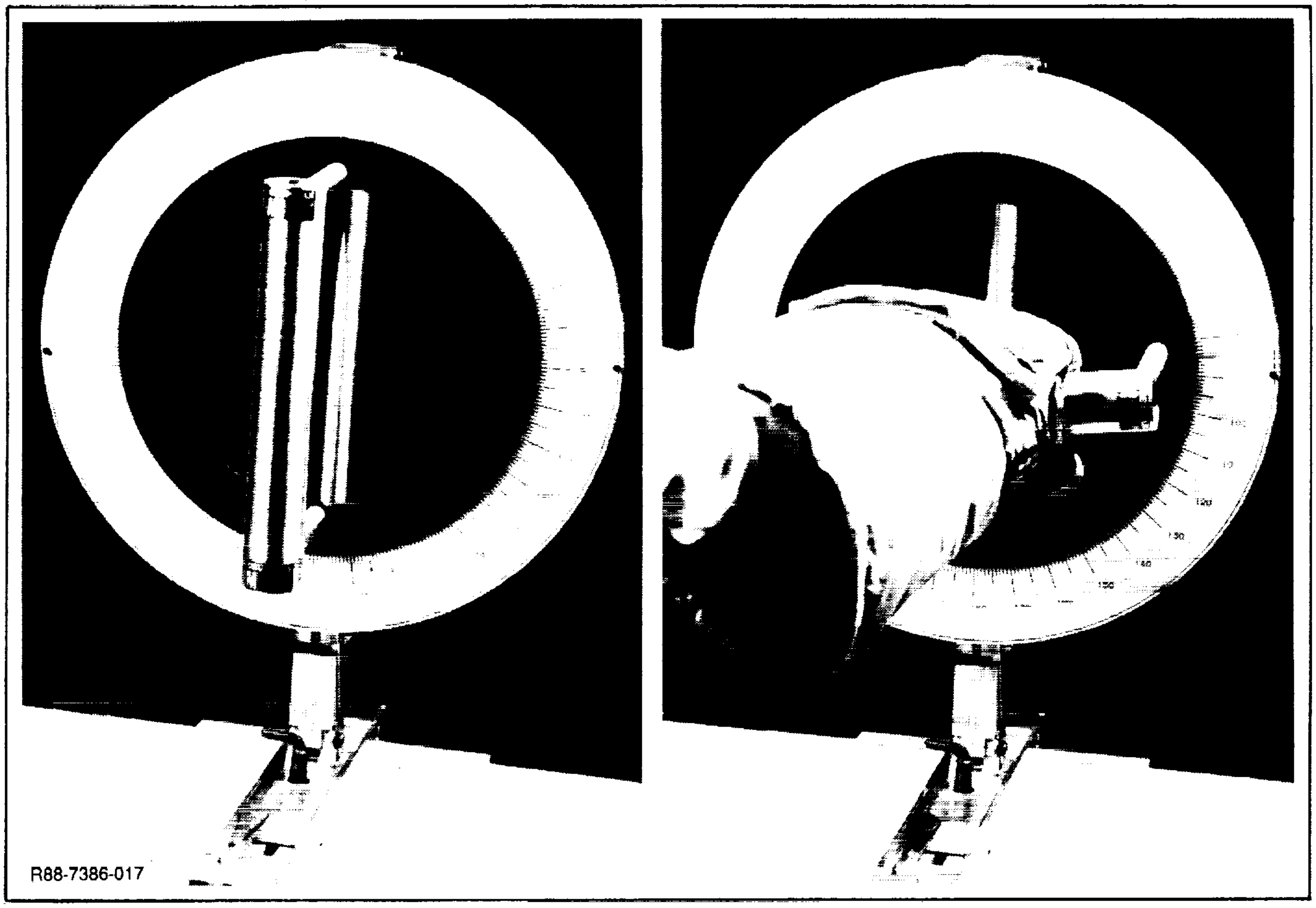

Fig. 4-7 D-Handle Device for Measuring Wrist Pronation & Suppination

finger. Digits 3-5 were allowed to provide support to the lateral side of the index finger. In addition to maximum key pinch force, maximum torques in both suppination and pronation directions were assessed.

The cylinder grip is the most common type of grip motion and was employed as the measure of hand grip force. The cylinder grip was measured as the force applied in a power grip with the wrist in neutral position (thumb up) for standardization. Maximum wrist (cylinder grip) torque is also measured in both suppination and pronation directions.

For each test two trials are obtained using the Baltimore Therapeutic Equipment (BTE) Co. Work Simulator. Figure 4-9 shows the tools which were attached to the

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Fig. 4-8 ROM Test Support Stand

BTE to measure the strength parameters. Also shown are tools that are attached to the BTE. Not shown is a hand held dynamometer used to measure maximum "cylinder" grip strength. The BTE provided all measures in in-lbs, the dynamometer measured in lbf. A copy of the data form is provided in Appendix B.

4.3.5 Tactile Perception

The assessment of tactile perception involved several tests. The determination of test methods for tactile perception parameters was not as straightforward as for range of motion or strength parameters for several reasons. First, the parameters often involve subjective judgment on the part of the test subject, therefore, the measurements are not as well calibrated. Second, tactile perception has not been studied in conjunction with gloved hand capabilities as often as other capability areas. Hence, there is little basis in the literature to design tests. Those tests which are available have been developed for bare hand capability assessment and,

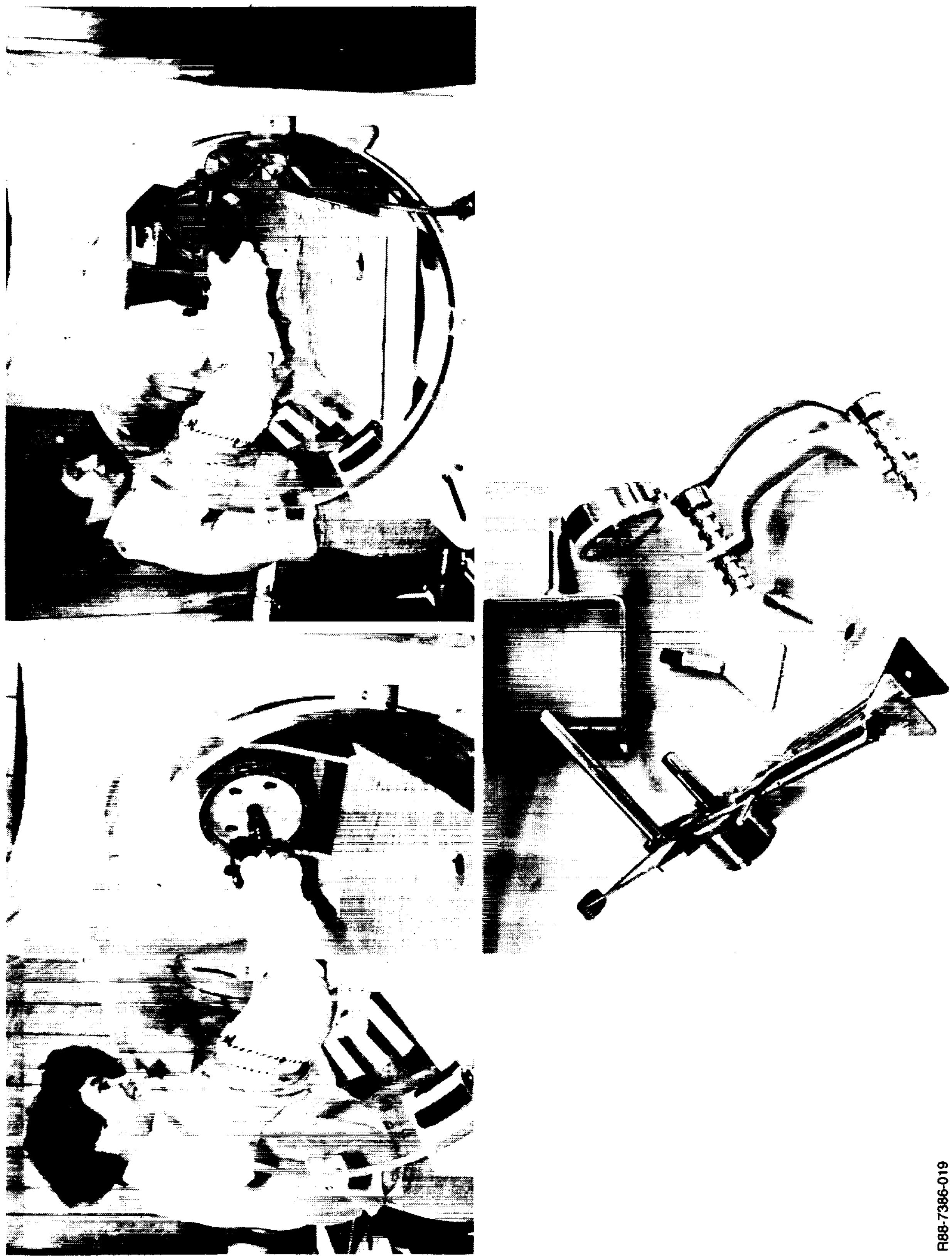

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Fig. 4-9 BTE Tools Used to Access Strength Parameters

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therefore, are too fine in resolution to be sensitive within the capability range of the gloved hand. Three different tests were developed to assess two-point discrimination object shape and size discrimination and perception of the necessary grip force to hold an object.

4.3.5.1 Two-Point Discrimination - Two-point discrimination is one of the classic indicators of tactile perception(25) and has been found to be well correlated with other parameters of tactile perception such as vibration sensitivity and pressure detection(26). The traditional method of assessing two-point discrimination is with a two-point aesthesiometer. This method is not well suited to gloved hand assessment nor is it easily accomplished within a glove box. A variation on the aesthesiometer was developed by Mackworth(27) which required subjects to decide when the edges of a V-shaped instrument were separated. Peacock(28) and Taylor and Berman(29) used a "V-Test" to determine two-point thresholds of gloved subjects. The Peacock study utilized a pressurized glove box, as well. The subject was required to move a finger along two straight edges positioned in a V-shaped configuration. The straight edges were calibrated and the gap width at the point where the two edges were perceived as separated was recorded. This method provides a simple and tested means of determining two-point thresholds and was adopted in this study.

Previous applications of this method have a potential bias, however. Since only a V-shaped instrument was used, subjects knew that they would detect two points at some point along the instrument. Hence, they may have had a bias to detect two points before they would have in an unbiased test. To minimize this problem, a V-shaped instrument was designed composed of two straight edges which were adjustable to provide a gap or no gap (see Fig. 4.-10). Ten trials were conducted and the blindfolded subject does not know on any one trial if a gap would be present or not. The index finger tip was used. The V-shaped instrument was composed of two 15 cm straight edges connected at one end and with a maximum gap of 1.5 cm at the other. (See Appendix C for specific details.) A copy of the data form is provided in Appendix B.

4.3.5.2 Grip Force Control Perception - One aspect of tactile perception which is very important to EVA is the perception of the amount of force required to hold an object. This is a function of the coefficient of friction between the object and the hand/glove and the object's weight. Subjects wearing gloves have been found to

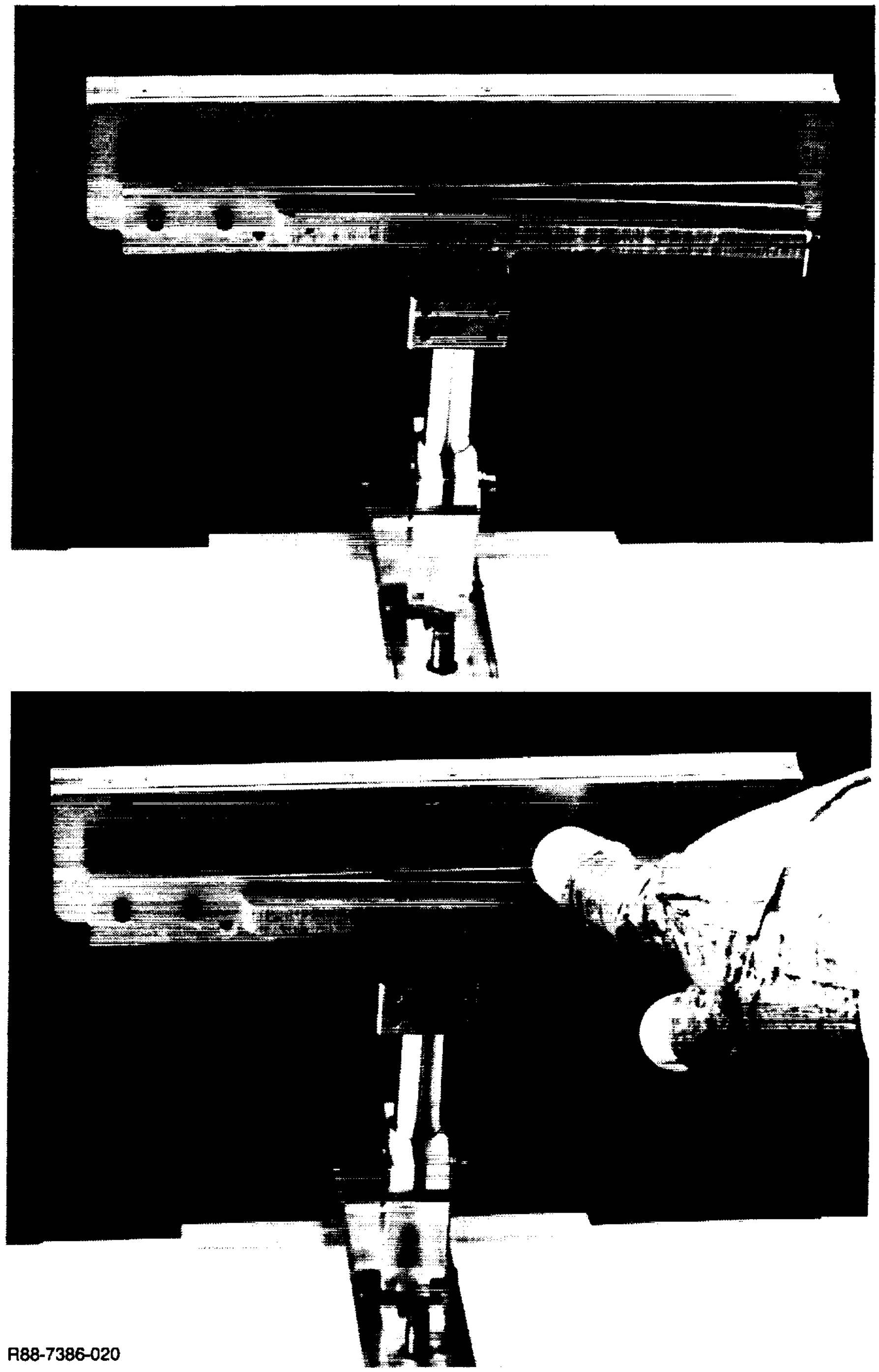

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Fig. 4-10 Two-Point Discrimination Instrument

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handle objects with excessive force(30). Using excessive force to handle objects would cause the EVA crewmember to become fatigued more quickly. In addition, over a long term the use of excessive force has been associated with conditions such as carpal tunnel syndrome and tendonitis. Ideally, one wants to design a glove which allows objects to be handled with the minimum force required to prevent slippage. Minimizing these forces not only reduces fatigue but also reduces the likelihood of damage to delicate objects being handled.

Westling and Johansson(31) have developed an innovative technique to assess the factors which influence force control during precision grip. The technique allows the applied grip force to be related to the vertical lifting force and the slipping force for various coefficients of friction between the hand and the test fixture. By having weights hidden from view, vision is excluded and grip force control is influenced by the hand perceived weight of the object, the perceived coefficient of friction, and the subject's own safety margin. This safety margin is the difference between the grip force employed and the minimal force to prevent slipping.

In slip studies, it was found that the applied grip force is critically balanced to optimize motor behavior so that slipping is prevented, but excessively high grip forces are avoided.

Experiments on subjects with local anesthesia indicated that the mechanism for this control feedback is the skin mechanoreceptors. The impaired tactility resulting from pressurized gloves can be expected to alter this feedback and thus the control mechanism. Another interesting finding in the above study was that highly manually dexterous subjects tend to employ a lower safety margin which might imply that such individuals would be less subject to fatigue.

An instrument was developed for this EVA glove study similar to that described by Westling and Johansson, except that position sensing is eliminated since it is redundant in purpose to the vertical force gauge (see Fig. 4-11 and Appendix C). The grip fixture has interchangeable machined acrylic surfaces which are varied to provide three different coefficients of friction. The subject's task was to pick up the fixture employing a comfortable grip force, hold it for a few seconds, and then gradually reduce the applied grip force until slippage occurs. The grip force was

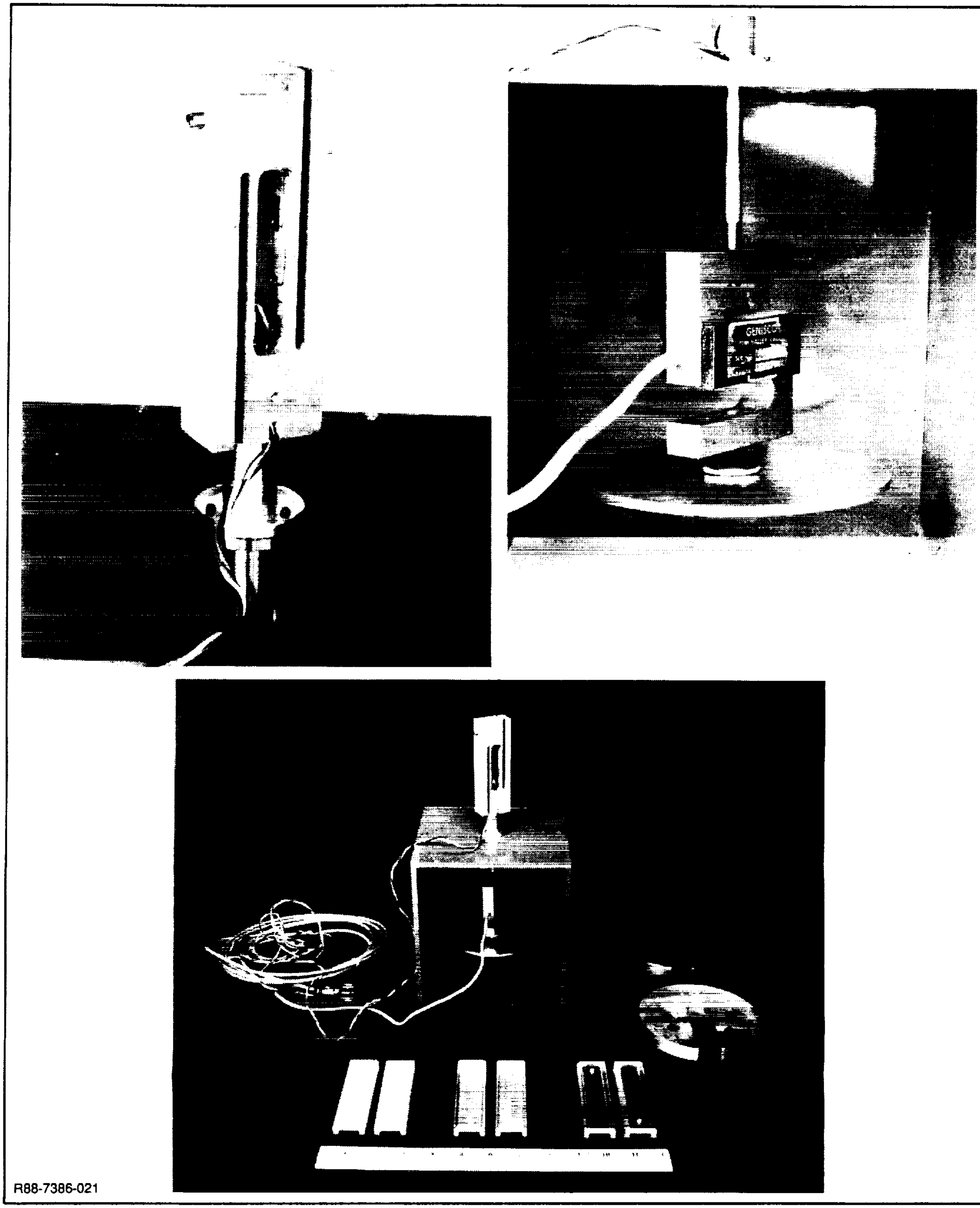

Fig. 4-11 Grip Force Control Perception Measuring Instrument

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constantly recorded by strain gauges and the vertical force strain gauge detected and recorded slippage. The grip force at the time corresponding to slippage was recorded as the minimal grip force to prevent slippage. The difference between sustaining grip force and slippage grip force was calculated as the safety margin.

The test was then repeated with different gripping surfaces and different weights. The weights were concealed from the subject's view hence he or she did not know on any given trial how much weight must be picked up. A total of eight trials were conducted resulting from an orthogonal combination of weight (one and three lb), handle (smooth and course), and grip type (palm and fingertip). An analysis of this data indicated how the safety margin was affected by the use of pressurized gloves as well as how changes in coefficient of friction, weight, and type of grip affect the safety margin. These analyses helped assess the hypothesis that the EVA crewmember will employ greater safety margins to compensate for the loss of tactility. A copy of the data form is contained in Appendix B.

4.3.5.3 Object Identification - Tactile object identification is a complex aspect of tactile perception that is related to other hand capabilities such as dexterity and to higher aspects of cognitive processing related to pattern recognition and identification. To test for object identification sets of objects in four basic shapes (sphere, cylinder, cube and rectangular parallelepiped) over a range of three sizes (small, medium, and large) were used.

The dimensions of the objects within each size were determined by equating the objects volume for sphere-cube and cylinder-rectangle pairs (see Table 4-4). For testing the objects are arranged on a "carrousel-type" device (see Appendix C) in a variable but predefined order which could be changed from one test session to another (see Fig. 4-12). The subject could not see the test object but located it by feeling the guide post. The subject's task was to identify the object's shape and size. After identification the carrousel was rotated to bring the next object in line with the guide post. A copy of the data form is provided in Appendix B.

4.3.6 Hand Dexterity Assessment

For the purposes of this study, three aspects of dexterity were assessed. The first task used a pegboard requiring precise hand positioning. The second task was a nut and bolt assembly task requiring the fingers to grasp and manipulate small

Table 4-4 Object Recognition Test Items

Shape	Parameters	Size, in. Small	Medium	Large
Sphere	Diameter Volume	.25 .01	.50 .06	.75 .22
Cube	Side Length Volume	.20 .01	.40 .06	.60 .25
Cylinder	Diameter Height Volume	.25 .33 .02	.50 .65 .13	.75 .98 .43
Rectangular Prism	Width Height Length Volume	.20 .20 .40 .02	.40 .40 .80 .13	.60 .60 1.2 .43

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objects in coordinated actions. The third task was a rope tying task requiring two-hand dexterity and coordinated actions between the fingers of both hands to manipulate flexible objects.

While a wide range of commercially manufactured, standardized tests of dexterity are available and have been extensively used in gloved-hand testing, two limitations are common. First, many of the standardized tests are work constrained and time variable. For example, the subject is required to insert 30 pegs in a board and the time required to complete the task is recorded. This is troublesome, however, since it may confound dexterity with fatigue. The longer one works the more the effects of fatigue come into play. A modification in the procedure to make tests time constrained and work variable is preferred, i.e., insert pegs for one minute and the number of pegs inserted is recorded as the dependent variable. Such an approach minimizes the influence of fatigue. Whenever possible this modification to typical dexterity tests was implemented.

The second problem is learning effects. Since dexterity tests tend to be more complex than Level 1 tests, the changes in performance over trials become a more significant problem. Wherever possible, dexterity tasks should be kept simple so that performance begins to asymptote after few trials. In the selection of tests for this study, commercially available tests and novel tests reported in the literature

Fig. 4-12 Object Identification Stimuli & Presentation Device

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were assessed to determine (1) their susceptibility to learning effects and (2) their ability to be converted to a time constrained task. As a result some common dexterity tests, such as the Hand Tool Dexterity Test, were rejected because studies which used the test reported performance improvements even after 20 trials. By contrast with peg board tasks, subjects typically approach an asymptote after three to five trials. These factors were considered in the dexterity testing approaches which follow.

4.3.6.1 Pegboard Test - The overwhelming test of choice in the literature for dexterity is the Purdue Pegboard. The test has a long history in hand research and has become a standard instrument in the analysis of gloved hand capabilities. The U.S. Air Force has recently included it as the recommended finger dexterity test in a standardized test battery of manual performance(31,32).

Dexterity comparisons from the bare hand to the gloved hand are very likely to be related to the size of the objects handled. Further, within the context of EVA equipment and mission planning the relationship of dexterity to object size is very important. The Purdue is based upon a single peg size which is very small and may be near the lower limit of EVA gloved hand capability. In addition, the Purdue requires considerable arm movement and therefore, complicates the isolation and assessment of hand dexterity.

For this study, a modified pegboard task was employed (see Fig. 4-13 and Appendix C). The test required the subject to grasp a peg, remove it from the hole, turn the peg around and reinsert it in the hole. The number of reinsertions completed in 30 seconds was recorded. This procedure minimized arm movements. The pegs were rectangular to require more precise manipulation than round pegs. Three sized pegs were used. Each was square at the end with side and length dimensions of 3/16"-3", 5/16"-4", 7/16"-5". The pegs fit snugly in the holes. The subject worked with only one peg at a time. If a peg is dropped the subject selected one of the spare pegs of the same size located at the top of the apparatus and resumed. An error was recorded for dropped pegs. Following each 30 second trial a one minute rest period was given followed by the next trial. When completed, the test conductor removed the pegs and replaced them with the next size peg to be tested. Preceding the trials in each condition, the subject was given a practice trial with each peg size. A copy of the data form is provided in Appendix B.

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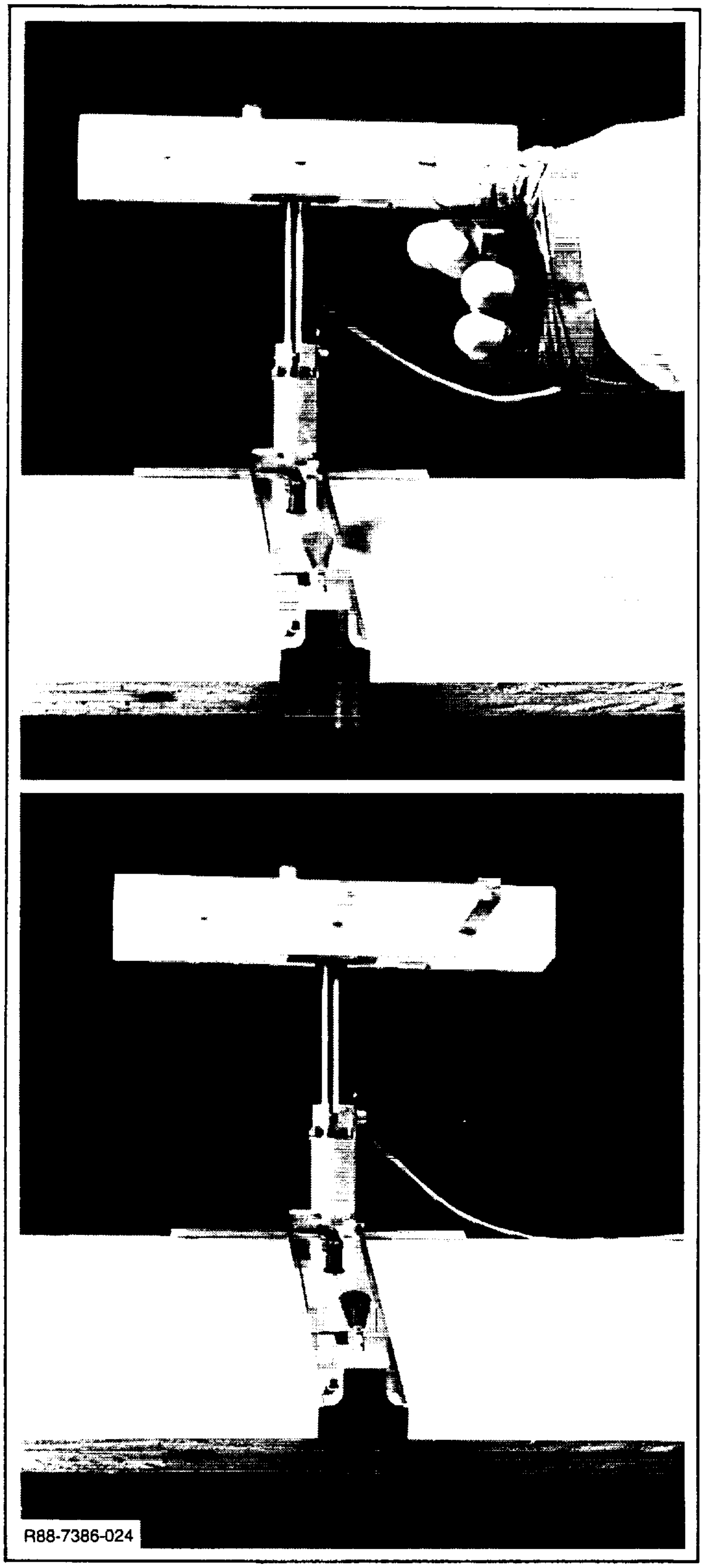

Fig. 4-13 Pegboard Test Instrument

4.3.6.2 <u>Nut & Bolt Assembly Task</u> - Three different sized nuts and bolts were used following the same rationale provided in the discussion of the pegboard test. The bolt lengths and diameters were 1" by 5/16", 1-1/2" by 1/2", and 2" by 5/8". The nuts and bolts for each size were arranged into boards with one board for each size (see Fig. 4-14). To minimize fatigue, the subjects were asked to grasp a nut/bolt assembly and to unscrew the bolt then to screw the nut on the bolt only five threads (to eliminate the fatiguing and redundant action required to torque the nut). A stud was positioned through the bolt stopping the nut at the desired location. The subject then dropped the assembly and moved on to the next. If a nut and/or bolt was dropped prior to assembly, the subject was instructed to select another assembly rather than to "fish" around for the lost piece. Drops were recorded as errors. Like the pegboard test, each subject had one practice and two test trials for each size. The number of assemblies and errors in 30 seconds at each size was recorded for each trial.

4.3.6.3 <u>Knot Tying Task</u> - Pegs, nuts, and bolts are all rigid objects which can be felt through a glove and manipulated more easily than flexible objects such as a thermal blanket. Consequently, a knot tying task was included in the test to evaluate dexterity for flexible object manipulation. The subject was asked to tie one knot in each of two ropes. Each rope was 36" long and the diameters were 0.25" and 0.5". The ropes were mounted to a support board (see Fig. 4-15). This task was timed and two trials with each diameter were performed. Like the other dexterity tasks, one practice and two test trials were provided.

4.3.7 <u>Fatigue Assessment</u>

As indicated earlier, fatigue can be conceptualized along three dimensions: physiological (i.e., muscle fatigue), performance decline (endurance), and subjective (i.e., psychological perception of fatigue). All three of these dimensions were assessed within a single test protocol. Each of the assessment methods are briefly described followed by a description of the protocol.

Physiological fatigue was assessed by recording electromyographic (EMG) signals from the muscles of interest. The EMG is defined as the electrical activity associated with a muscle contraction. Muscle fatigue can be objectively measured by analyzing the change in the frequency components of the EMG signal that occurs when a muscle contraction is sustained or repeated (for a review, see De Luca, 33).

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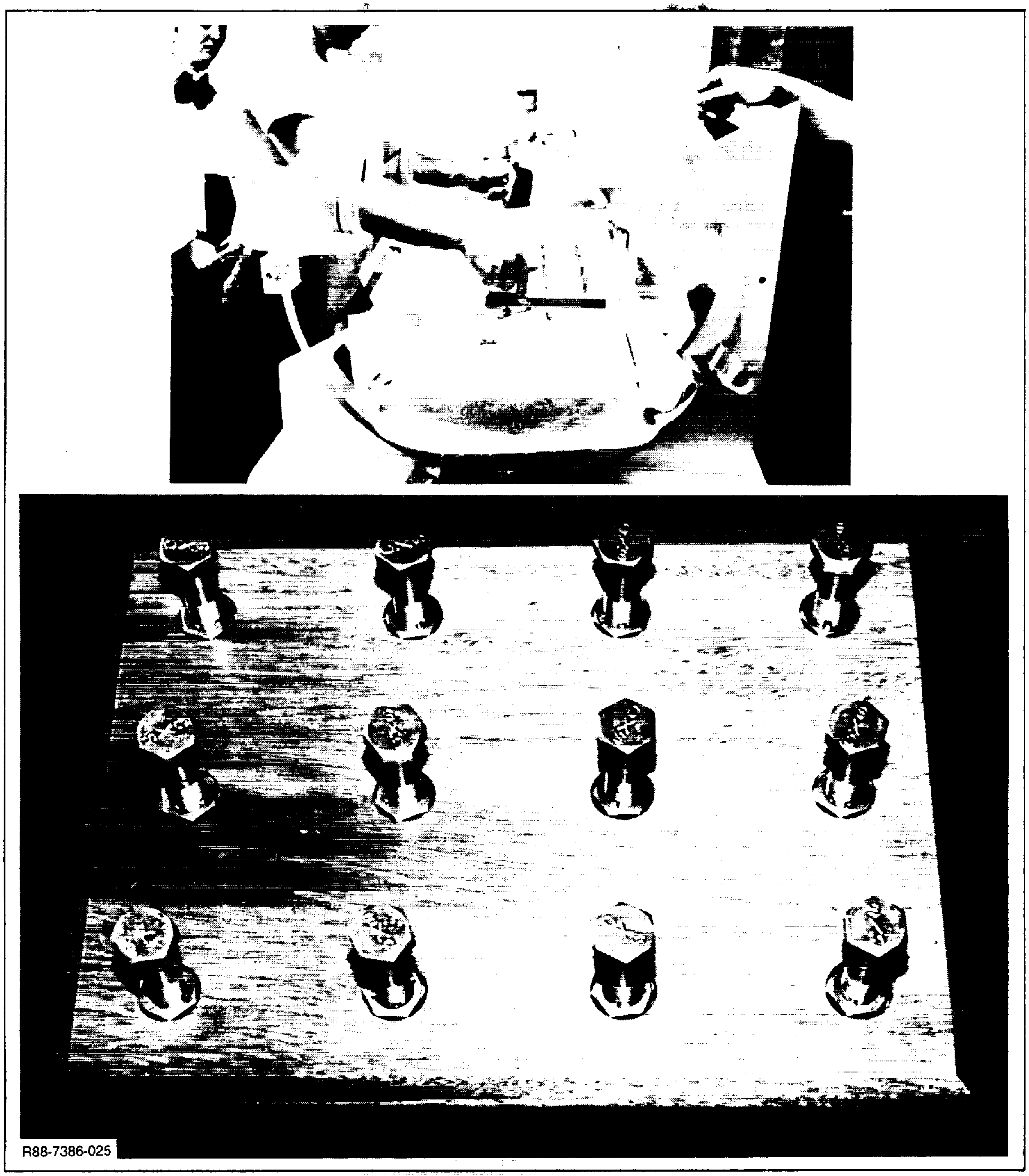

Fig.4-14 Nut & Bolt Assembly Test Board

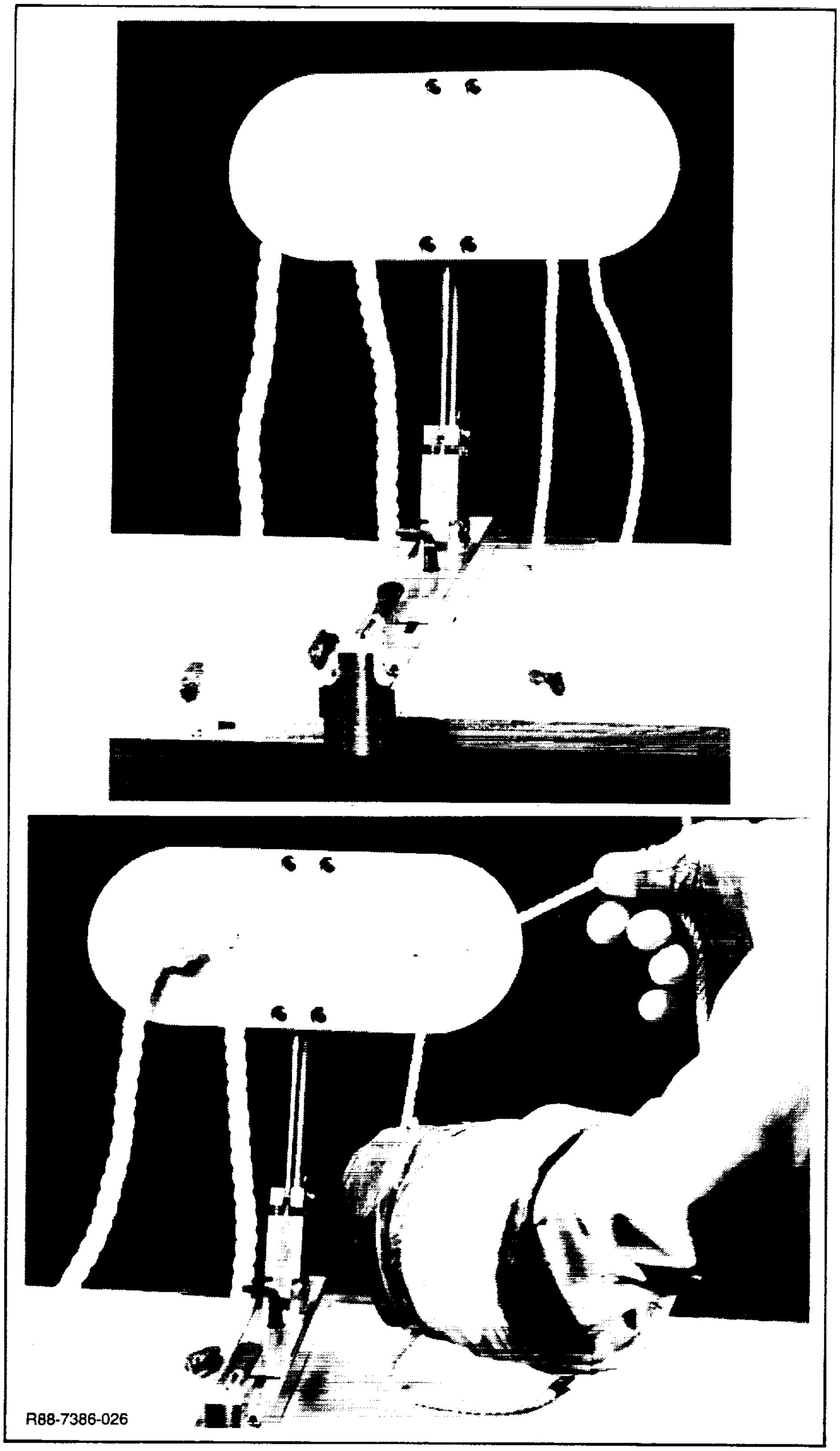

Fig. 4-15 Knot Tying Task Board

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It has been well documented that these changes in the EMG signal can be directly related to the biochemical correlates of muscle fatigue(34-39). For instance, it has been demonstrated empirically and mathematically that the conduction velocity of the EMG signal is slowed as the pH of the muscle decreases by the accumulation of lactic acid and other metabolic end-products of metabolism. This change in conduction velocity can be measured as a change in the frequency content of the EMG.

The preferred way of monitoring this change is to measure the reduction in the median frequency as a muscle contraction is sustained. The median frequency is the frequency that divides the EMG power density spectrum into halves of equal power. This definition of fatigue has certain advantages over the more popular conception of fatigue as a failure point or inability to maintain a desired force output. Biochemical correlates of fatigue are known to be changing long before mechanical failure occurs and, therefore, fatigue is representative of a process rather than a single event.

Force dependent measures of fatigue can be seriously influenced by psychological components such as motivation and cooperation of the subject. Median frequency measures are less susceptible to these influences because they indirectly measure the underlying physiological processes associated with fatigue which cannot be voluntarily controlled. This method has further advantages that are particularly relevant to quantifying fatigue related to EVA Glove use. Most gripping tasks involve the activation of more than one muscle group. There is currently no in vivo method available to measure the actual force output of synergistic muscles that are coordinated during a task. Therefore, it is not possible to obtain a dynamic, force-related measure of fatigue for each of the muscles active during gripping. However, it is possible to measure the EMG from individual muscles via surface electrodes placed over the muscles of interest and evaluate the fatigue in each of these muscles by computing the change in median frequency. If metabolic or localized fatigue were present, we would expect to measure a decrease in the median frequency valve as more fatigue trials were produced.

We selected this technique as an ideal way for evaluating muscle fatigue for EVA glove use. In addition, interaction between synergistic muscles can be identified by comparing the concurrent EMG activity for each of the muscles monitored. Furthermore, since surface EMG electrodes are non-invasive and low profile, they can be placed within the EVA glove without interfering with the tasks being measured.

The subjective dimension of fatigue was assessed through two methods. First, ratings on a five-point scale were obtained during the fatigue protocol to ascertain the subject's perception of fatigue while performing a task. Second, when the task was completed the subject filled out a fatigue questionnaire.

Change in work over time provides an indication of the performance decay attributed to the gloves. A comparison of performance decay and the shift in the EMG median frequency provides an understanding of the relationship between physiological fatigue (metabolic cost) and performance decay.

A general method for assessing fatigue was developed after a series of preliminary trials were conducted at the Neuromuscular Research Center (NMRC) at Boston University to formulate the most appropriate protocol of assessing fatigue associated with EVA Glove use during a gripping task. Since gripping normally involves different parts of the forearm and hand muscle that may not always be concurrently active, we decided to detect the EMG from more than one muscle. We selected two muscles of the hand near the thumb (flexor pollicis brevis and first dorsal interosseous muscles) and two muscles located in the forearm that function to stabilize the wrist in extension and flex the fingers at the ulnar side of the hand (extensor carpi ulnaris and flexor digitorum superficialis muscles). We felt it was necessary to monitor muscles from different parts of the hand because, during normal gripping, the subject is free to use different combinations of muscles to produce the same net force output. Another, more practical reason for multiple electrode readings was to ensure a certain amount of redundancy in case of electrode failure or the presence of unexpected signal artifact or interference on a particular EMG channel.

The actual test procedures implemented were a combination of brief static contractions at regular intervals between more prolonged, dynamic contractions. These two type of contractions closely approximate the static and dynamic ways the hand can be used to elicit fatigue. We opted to use a dynamic task of opening and closing the hand against slight resistance to induce fatigue in the forearm and hand.

It was felt that this kind of activity is functionally related to the tasks encountered during EVA glove use.

The physiological fatigue state of the muscle initially and at specified time intervals into the dynamic work task were monitored by brief, static contractions using a hand dynamometer. EMG data were collected and analyzed only for these brief static contractions since the EMG signal is more stationary (i.e., less variance in the signal) under this condition than during dynamic contractions. Length changes of the muscle and motion artifact are often problems in dynamic contractions and they can complicate the analysis of the EMG signal for calculating the median frequency parameter. The cumulative fatigue effects of the repeated dynamic contractions were compared for the three test conditions by measuring the median frequency at the beginning of each of the static contractions.

These results from the static contractions can be thought of as a quick measure of the biochemical state of the muscle (i.e., accumulation of lactic acid and other metabolic end products) that have resulted from the repeated opening and closing of the hand against resistance.

In much the same way, recovery from fatigue was monitored by measuring the initial value of the median frequency (the value at the very beginning of the static contraction) at regular time intervals during the "rest" period following the seventh, or last fatigue trial. We were interested in the time needed for the median frequency to return to its baseline value during the "rest" period. Recovery from fatigue was included because it is easily measured and, more importantly, is of practical value in determining whether a particular glove condition (or design) has an impact on the duration of fatigue effects.

This is also helpful in understanding the fatigue process since the resultant fatigue at any one time is a function of metabolite production and removal. In other words, recovery processes occur even during an active state of a muscle. Oftentimes it is difficult to assess how effective this recovery process is unless you can isolate it, e.g., during a rest period following a prolonged active state of the muscle.

The detailed fatigue protocol was as follows. First the subject was prepared for testing by placing low-profile, surface electrodes over the muscles of interest for EMG recording. The second step was to determine the subject's maximum voluntary contraction (MVC) by squeezing a hand held dynamometer in both the bare hand and gloved hand condition. The third step was to begin the fatigue sequence. The sequence consisted of seven cycles where each cycle was composed of a 10 second isometric contraction held at 20% of the subject's barehand MVC followed by a one minute isotonic gripping task.

As indicated above, the gripping task was designed to produce hand fatigue associated with the flow and fabric work of EVA glove manipulation. A "bicycle brake type" gripping fixture was developed and linked with a BTE work simulator (see Fig. 4-16) for this task. A small resistance was provided by the handle. Subjects' rate of gripping was held constant at approximately 45 squeezes per minute. The amount of work performed was calculated by the BTE for each cycle. These data were used to analyze performance decline over cycles. After the one minute gripping tasks, the subject picked up a hand-held dynamometer and performed the 10 second isometric contraction as per the logic described above. At the end of each isometric contraction the subject gave a subjective fatigue rating on a five-point scale (see Table 4-5). These ratings were intended to provide a "real-time" estimate of the fatigue being experienced.

Following the seven fatigue cycles, a rest sequence was initiated. A rest cycle consisted of a 5 second isometric contraction using the dynamometer (for recording of EMG data) followed by a rest period of between 30 seconds and two minutes. The purpose of the rest cycle was to examine EMG (physiological fatigue) and performance recovery rates. On the last cycle the subject gave a maximum contraction (rather than a 20% MVC).

In addition to the EMG, gripping task work performance, and subjective data, the force maintained on the dynamometer during isometric contractions was recorded when/if subjects were unable to sustain a 20% MVC. Hand skin temperature was also recorded on a test conductor's form (see Appendix B) before, during, and after the procedure.

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Fig. 4-16 Gripping Fixture on Cable Link to BTE Head Used in Fatigue Protocol

Table 4-5 "Real Time" Fatigue Rating Scale

1.	Your hand feels the same as when you began squeezing the handle; no noticeable fatigue
2.	Light fatigue - level between 1 & 3
3.	Your hand feels some resistance to squeezing the handle; moderate fatigue
4.	Fatigue - level between 3 & 5
5.	Your hand is unable to effectively squeeze the handle; complete fatigue

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When the fatigue/rest sequence was completed the subjects were asked to provide a global fatigue rating on a nine-point scale (see Fig. 4-17). Due to the nature of the fatigue protocol, only one test condition, e.g., barehand, gloved hand, etc, was evaluated per day. This provides sufficient time for the muscles to fully recover.

4.3.8 Comfort Assessment

Comfort encompasses perhaps the most difficult set of hand parameters to quantify because it is unavoidably based on subjective evaluation. A review of the literature revealed 11 studies (see Appendix A) which assessed comfort and all utilized subjective methodologies. Baddley(40) defined an objective set of measures of glove characteristics (tenacity, suppleness, and protectiveness) related to comfort and performance. The objective measures were well correlated with subjective evaluations of those characteristics, hence subjective ratings were developed for this study.

Comfort was also different from other areas in that the data applied mainly to glove conditions only, i.e., many of the comfort parameters were irrelevant to bare hand test conditions. The assessment of comfort was none the less important to aid in the interpretation of test results in other capability areas. For example, the reason that one subject performed significantly different than others may have reflected severe discomfort rather than fatigue or lack of tactility.

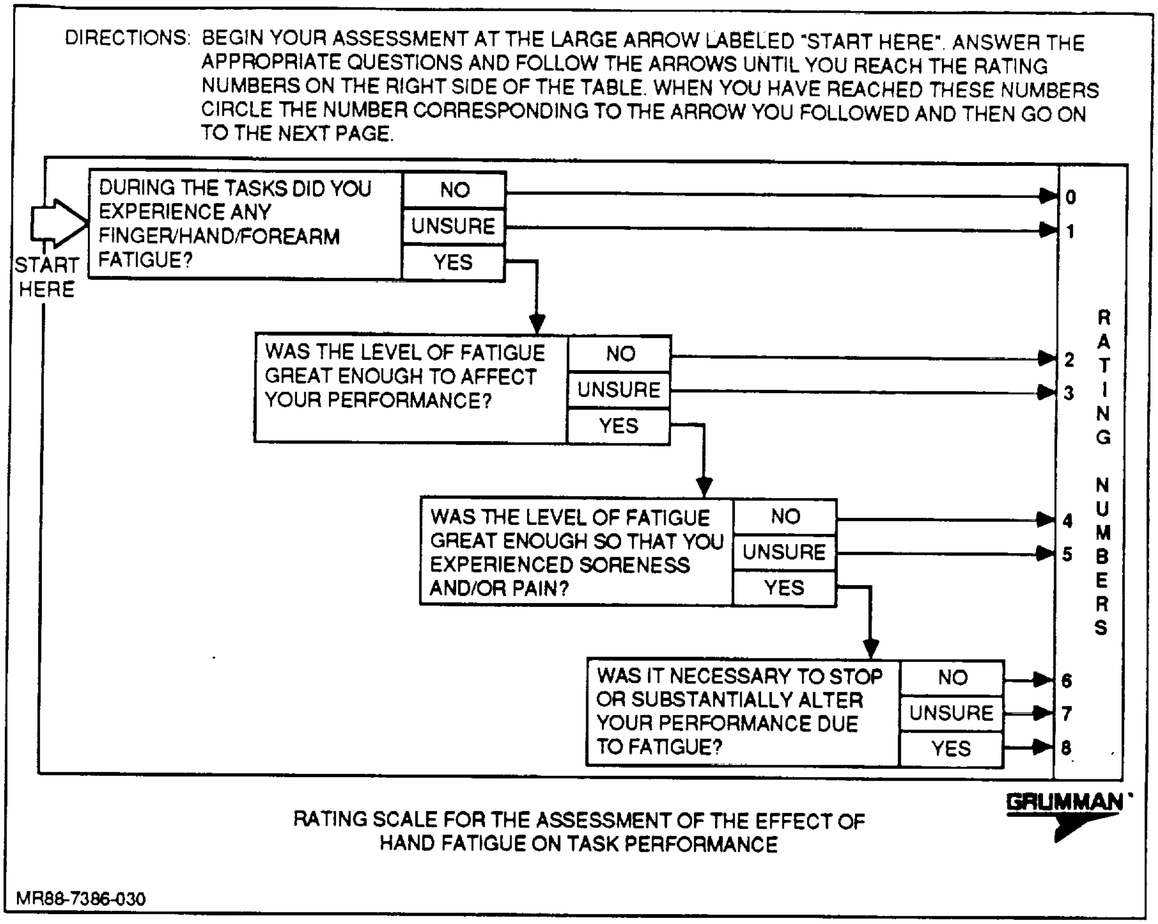

Fig. 4-17 Global Fatigue Rating Scale

Comfort was assessed using a series of rating scales and questionnaires assessing the following aspects of comfort: (1) the subject's rating of the effect of comfort/discomfort on task performance, and (2) the subject's rating of glove-hand interaction, hand environment, and glove fit.

The subject's assessment of the effect of comfort/discomfort on task performance was made on a structured nine-point rating scale (see Fig. 4-18). It is intended as a global assessment. The second rating scale (see Fig. 4-19) was developed to provide more specific information about glove-hand interaction, the hand environment, and fit. Subjects rated the extent to which problems such as chafing, cutting, pinching, and numbing were experienced and indicated the location of these problems on diagrams of the hand. In addition, they rated the hand temperature or perspiration problems.

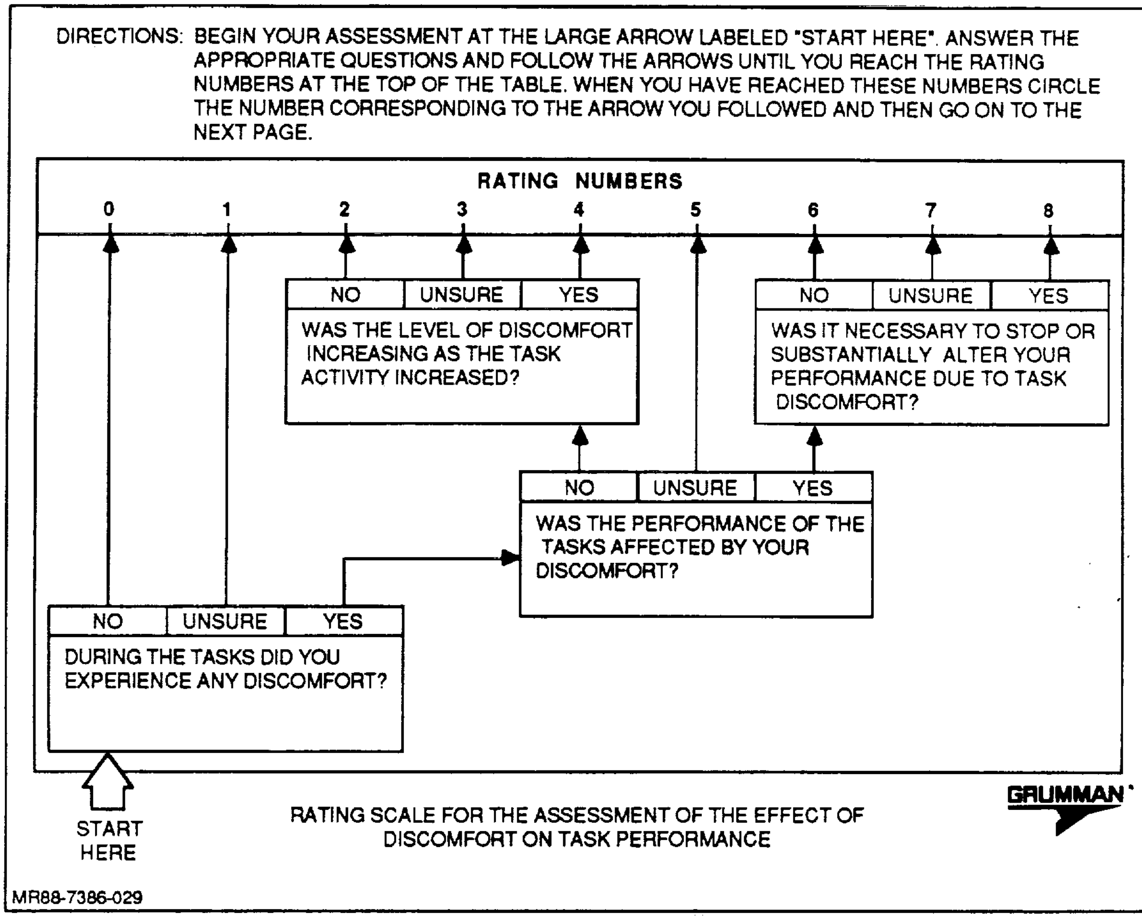

Fig. 4-18 Post Hoc Comfort Rating Scale

FIT AND COMFORT EVALUATION

Directions: For each item no. (column 1) listed in table below, rate the impact that item has on your ability to accomplish tasks while wearing the gloves. Perform this rating by placing a check in the proper box under column 4. Space has been reserved at the bottom of the table for any additional discomforts that you may have experienced. When you have completed this table, please go to the next page.

1 ITEM NO.	2 NATURE OF DISCOMFORT	3 DEFINITION	4 IMPACT ON GLOVE PERFORMANCE NONE	 MODERATE	 GREAT
1	CHAFING	To irritate or make sore by rubbing.			
2	CUTTING	To pierce, gash or tear; to scratch or scrape			
3	PINCHING	To squeeze, cramp or press.			
4	NUMBING	To lose feeling.			
5	HAND TEMPERATURE	Hands/fingers become hot.			
		Hands/fingers become cold.			
6	HAND PERSPIRATION	Excessive hand/finger wetness.			
		Dry feeling of hands/fingers.			
	Specify, if any				
	Specify, if any				

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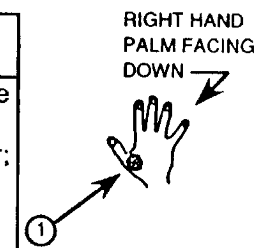
Directions: Refer to table 1 on this page and use the hand sketches to indicate the general area(s) where specific types of hand discomfort were experienced. Extra space has been left at the bottom of table 1 so that you may indicate any additional discomforts you may have experienced.

Example: If CHAFING was experienced around the right thumb knuckle than label this region using the item no. (1) for CHAFING.

ITEM NO.	NATURE OF DISCOMFORT	DEFINITION
1	CHAFING	To irritate or make sore by rubbing.
2	CUTTING	To pierce, gash or tear; to scratch or scrape.
3	PINCHING	To squeeze, cramp or press.
4	NUMBING	To lose feeling.

Table 1



After completing this form go on to the next page.

ohara04

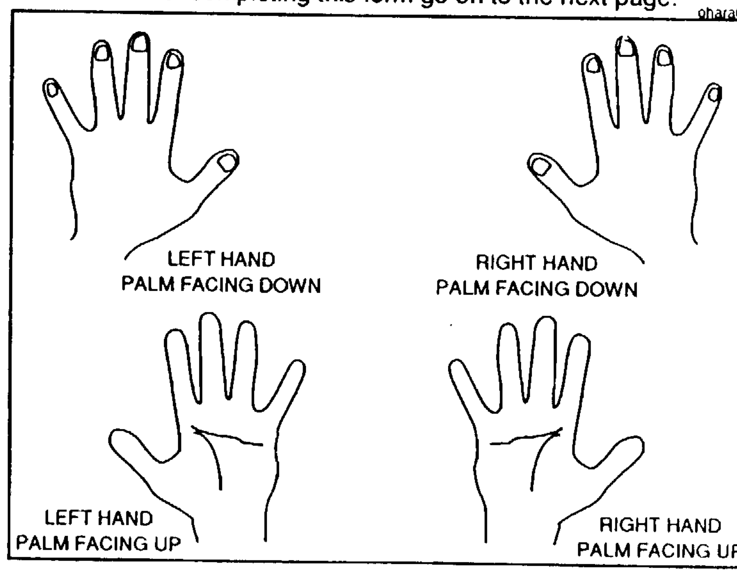


Fig. 4-19 Glove Comfort Evaluation Forms

5 - PHASE II TEST PROGRAM RESULTS

5.1 APPROACH TO DATA ANALYSIS

The main purpose of the data analysis was to analyze the effects of the independent variables on the dependent variables or measures of hand performance. There were two different types of independent variables included in this study: Principal IVs and Test Specific IVs. The principal IVs were: hand size and glove condition. The latter incorporated both the effects of the glove alone and of the incremental effects of pressure:

- Glove Effect = M (Barehand) - M (Glove/0 psid)
- Pressure Effect = M (Glove/0 psid) - (Glove/4.3 psid)

where M = the average of the dependent variable being analyzed over all test subjects (excluding the female subject).

Each individual test had its own set of independent variables which were listed in Table 4-3. The analysis of any individual performance variable depends on the simultaneous influence of all independent variables in that test. The analysis and presentation of the test results will be organized by the individual test.

The overall approach to the data analysis was as follows. The data for each test were first analyzed for hand size effects. To accomplish this analysis a hand size variable was defined for each subject:

- Hand size = hand length x hand circumference

This parameter was then correlated with the performance data for each dependent variable. The correlation method was a Pearson Product-Moment (Pearson r) Solution. Separate correlations were calculated for each glove condition, i.e., barehand, glove/0 psid, and glove/4.3 psid (and glove/2.3 psid for the ROM tests).

The Pearson r describes the relationship between hand size and the dependent variable. If this relationship was not found to be statistically significant for a specific dependent variable, then the hand size variable was dropped from further analysis of that variable. If the relationship was found to be statistically significant, then hand size was factored into the subsequent analysis of the IV.

The Pearson r is comprised of a magnitude (between zero and unity) and a sign (positive or negative). As the magnitude of r approaches unity the relationship between the variables under investigation becomes significant. If r is positive, then as one variable increases so does the other; and, if r is negative, then as one variable increases the other decreases. For the tests conducted in this report, where the number of test subjects is equal to ten, a value of $r \geq |0.63|$ means that the chances of no relationship existing between hand size and the dependant variable under investigation is 1 in 20.

Following the hand size analysis, the data were analyzed for the effect of glove condition and the test specific IV, Tables of descriptive statistics such as frequency, mean, and standard deviation were prepared for each dependent variable. The data are also presented in graphic form (histograms and line graphics) to illustrate and highlight the relationships between IVs and DVs.

In each of the results sections that follow, the organization of the data presentation is:

- Summary of the independent and dependent variables for the test being presented
- Discussion of hand size effects for each DV
- Discussion of the glove condition and test specific IV effects for each DV.

The main data analysis was based upon the male subjects. We decided not to include the data for the one female subject in the analysis because we had only one "data point."

5.2 RANGE OF MOTION

Range of motion measurements primarily provide an estimate of restrictions on positioning the hand and phalanges imposed by the glove conditions relative to the bare hand. Each test subject went through the sequence of hand positions directed by the test monitor, while observing illustrations of the positions on a chart. Subjects were asked to extend to the maximum extension and hold. A Camcorder recorded the entire sequence.

Angle and length measurements were taken from a stop-action video cassette recorder display. This was done by using a transparent overlay over the screen and drawing the lines between the estimated points of joint rotation or along the lines of skeletal fixed position, such as the line of the forearm through the base thumb joint. The angles were then measured using a protractor.

Only the thumb opposition measurement had to be completely deleted because of improper positioning of the thumb and poor camera angle. However, other measures suffered somewhat from variability in extending to maximum, (indefinite or improper positioning), and inadequate control of position. The results were calculated for both the total data set and a reduced data set from which obviously bad points have been removed.

The effects of hand size were determined by correlating it with the range of motion angles. These data are presented in Table 5-1. Significant correlations were observed for MCP1 flexion in the glove-2.3 psid condition, MCP1 extension in the barehand condition, MCP2 flexion in the barehand and unpressurized glove condition, and for wrist pronation in the glove-4.3 psid condition. For all but wrist pronation the correlations were negative indicating that range of motion was decreased as hand size increased. In general, the correlations for MCP1 and 2 ROM were negative and high. The significant positive wrist pronation correlation indicated that the greater the hand size the greater the ROM. Since only 5 of the 56 correlations were significant the hand size variable was dropped from further analysis.

The average range of motion for each ROM parameter is presented in Table 5-2.

For MCP group ROM, flexion was mainly affected by donning the glove but pressure had little effect. The ROM in the unpressurized glove condition was 78% of barehand while in the glove pressurized to 4.3 it was 69% of barehand. For MCP group extension, a loss of ROM was observed across all conditions. In the unpressurized glove condition MCP group extension was 85% of barehand. In the glove-2.3 psid condition it was only 18% of barehand. Hence pressure was a major factor in extension but not flexion of the MCP group.

The results for MCP1 flexion and extension do not reveal any significant effects of the glove alone or the pressure differential. For MCP2 flexion, the unpressurized glove ROM was 80% of barehand. The value dropped to 65% of barehand in the glove 2.3 psid condition with little change thereafter.

Table 5-1 Average Correlations of Hand Size & Range of Motion

ROM Parameter	Glove Condition			
	Barehand	Glove-0 psid	Glove-2.3 psid	Glove-4.3 psid
MCP Group Flexion	-.17	-.38	-.22	.10
MCP Group Extension	.02	.28	-.03	.54
MCP1 Flexion	-.02	-.51	-.92*	-.52
MCP1 Extension	-.72*	.00	-.60	-.61
MCP2 Flexion	-.64*	-.63*	-.44	-.39
PIP1 Flexion	-.15	-.07	.36	.31
PIP1 Extension	.29	.02	.17	.14
PIP2 Flexion	.01	-.20	-.23	.08
Wrist Adduction	.35	.12	-.06	-.45
Wrist Abduction	.16	-.23	-.02	-.45
Wrist Pronation	-.12	.10	.32	.69*
Wrist Suppination	.20	.40	.41	.10
Wrist Flexion	.41	.59	.17	.43
Wrist Extension	.09	-.49	-.28	-.25

* Correlation is significant at the p>.05 level; critical r=.63 (df=8).
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The results for PIP1 flexion indicated a large drop in range of motion with the unpressurized glove to 29% of barehand flexion. The ROM actually increased with pressure to 49% of barehand in the glove-4.3 psid condition. The extremely low unpressurized glove ROM was probably artificially low caused by one extremely low score. It appears that PIP1 flexion was affected by donning the glove but not degraded further by pressure. The same pattern held for PIP extension. Extension was reduced to 69% of barehand in the unpressurized glove condition and was 62% in the glove 4.3 psid condition. Thus PIP1 ROM was primarily influenced by the glove itself.

Table 5-2 Average Range of Motion, deg

ROM Parameter	Glove Condition			
	Barehand	Glove-0 psid	Glove-2.3 psid	Glove-4.3 psid
MCP Flexion	71.1 (10.8)	55.4 (8.8)	50.8 (7.4)	48.9 (7.7)
MCP Group Extension	14.4 (10.7)	12.3 (11.9)	7.5 (13.3)	2.6 (12.9)
MCP1 Flexion	54.4 (9.0)	54.1 (8.3)	54.7 (7.7)	54.2 (7.3)
MCP1 Extension	-.6 (14.4)	8.6 (14.2)	2.11(13.0)	-.1 (10.6)
MCP2 Flexion	60.6 (14.8)	48.7 (12.1)	41.9 (6.1)	41.5 (13.4)
PIP1 Flexion	63.3 (15.3)	18.3 (18.5)	31.0 (16.9)	30.8 (12.8)
PIP1 Extension	37.5 (9.0)	11.1 (14.0)	12.2 (8.5)	9.4 (8.5)
PIP2 Flexion	89.2 (70.4)	61.8 (23.2)	61.0 (16.8)	55.7 (18.2)
Wrist Adduction	38.8 (8.9)	39.3 (12.3)	38.0 (5.9)	39.5 (7.3)
Wrist Abduction	37.7 (11.4)	36.5 (9.6)	30.5 (8.4)	29.1 (7.3)
Wrist Pronation	120.7 (21.7)	93.3 (22.2)	77.5 (32.3)	76.1 (37.1)
Wrist Suppination	136.9 (20.7)	127.8 (19.5)	116.3 (18.2)	103.2 (28.9)
Wrist Flexion	54.8 (15.8)	51.1 (10.1)	53.9 (7.1)	49.7 (7.7)
Wrist Extension	62.4 (9.1)	55.2 (7.0)	42.2 (6.4)	34.1 (8.5)

Table values are expressed in means; standard deviations are in parentheses.

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Like finger motions, wrist motions were differentially affected by the glove and pressure. Wrist flexion and adduction were little affected by glove or pressure. Wrist abduction was mainly affected by pressure. Little drop in ROM was observed with the unpressurized glove condition but performance dropped to 81% in the glove-2.3 psid condition and a little more in the 4.3 psid condition. Wrist extension, pronation, and suppination were affected by both glove and pressure.

Wrist flexion dropped to 86% of barehand in the unpressurized glove condition and to 65% and 55% in the 2.3 and 4.3 psid conditions. Wrist pronation ROMs were 77%, 64%, and 63% across the three glove conditions and suppination was 93%, 85%, and 75% of barehand performance across the three glove conditions.

To summarize the main effects observed on range of motion:

- No effect - MCP1 flexion, MCP1 extension, wrist flexion, wrist adduction
- Glove effect only - MCP group flexion, PIP1 flexion, PIP1 extension
- Pressure effect only - wrist abduction
- Glove and pressure effects - MCP group extension, MCP2 flexion, wrist extension, wrist pronation, wrist suppination.

5.3 STRENGTH

Hand strength tests evaluated the effects of the glove test condition and nine grip/pinch types on strength measures. Two data trials were obtained for each grip type. The two trials were averaged to provide data for analysis. Each was based on 10 data pairs. The critical r value for statistical significance based on 8 degrees of freedom and an alpha level of 0.05 is 0.63. Thus values of r exceeding 0.63 or less than -0.63 were regarded as statistically significant.

The effect of hand size was analyzed by correlating it with strength measures for each glove condition - grip type combination. Table 5-3 presents the entire matrix of correlations. From the values presented in Table 5-3 it can be seen that hand size generally was not significantly related to hand strength measurements. Three of the 27 correlations were significant at the 0.05 level: Cylinder grip force in the barehand condition and cylinder grip suppination/pulp pinch force in the glove/4.3 psid condition. In each case the correlation was positive indicating that the larger the hand size the greater the strength measure. The general relationships observed in the other correlations, although these were not significant, were:

- All cylinder grip correlations were positive and approaching significance
- Measures of force grips generally showed stronger positive correlations than the torque (pronation and suppination) measures of the same type of grip
- The average correlation differed little across glove condition but was slightly higher in the pressurized glove condition (0.36, 0.35, and 0.39, respectively).

While these trends are suggestive they were not statistically significant given the limited sample size utilized in this study. Since the overall relationship between hand size and strength was not significant, this variable is not considered in subsequent analyses of strength measures.

Table 5-3 Correlations of Hand Size with Hand Strength

Grip Type	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Cylinder Grip Force	.69*	.49	.58
Cylinder Grip Pronation	.63*	.53	.60
Cylinder Grip Suppination	.38	.33	.67*
Pulp Pinch Force	.41	.51	.65*
Chuck Pinch Pronation	.26	.50	.09
Chuch Pinch Suppination	-.24	.16	.35
Key Pinch Force	.44	.51	.47
Key Pinch Pronation	-.07	.03	.09
Key Pinch Suppination	.12	.12	.02

* Correlation is significant at the p>.05 level; critical r=.63 (df=8).

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The mean strength values as a function of glove condition and grip type is provided in Table 5-4 and illustrated in Fig. 5-1. The relationship between glove condition and strength measures was generally low. The only large effect of the glove was on cylinder grip measures. This was possibly due to the fact that it was the only "full hand" strength measure. Pinch tests generally involved little hand movement and, therefore, little glove resistance in the glove conditions. The biggest effect of glove condition was on cylinder grip maximum force measure obtained with the hand held dynamometer. The average barehand force was 122 lb with the unpressurized glove subject's strength reduced to 65% of barehand and when the glove was pressurized performance dropped to 53% of barehand. In cylinder grip pronation, the average barehand strength was 108 in-lb, but when the glove was pressurized the average strength was reduced to 81 in-lbs or 75% of barehand (see Fig. 5-1). There was little difference between the glove condition on the other strength measures.

Table 5-4 Average Grip Type Strength, in-lb

Grip Type	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Cylinder Grip Force	122.1 (35.28)	78.7 (18.46)	64.55 (22.68)
Cylinder Grip Pronation	107.95 (31.63)	105.6 (43.14)	81.30 (28.76)
Cylinder Grip Suppination	111.6 (44.31)	111.75 (28.48)	98.55 (36.19)
Pulp Pinch Force	242.4 (79.92)	250.95 (68.28)	240.75 (61.30)
Chuck Pinch Pronation	19.2 (5.38)	21.45 (4.25)	24.5 (8.78)
Chuch Pinch Suppination	29.85 (24.69)	26.25 (3.55)	27.00 (5.24)
Key Pinch Force	200.1 (75.08)	203.1 (50.26)	178.35 (44.61)
Key Pinch Pronation	34.50 (8.49)	39.3 (10.72)	35.7 (7.34)
Key Pinch Suppination	40.4 (11.8)	37.8 (12.14)	35.55 (11.59)

Table values are expressed in means; standard deviations are in parentheses.
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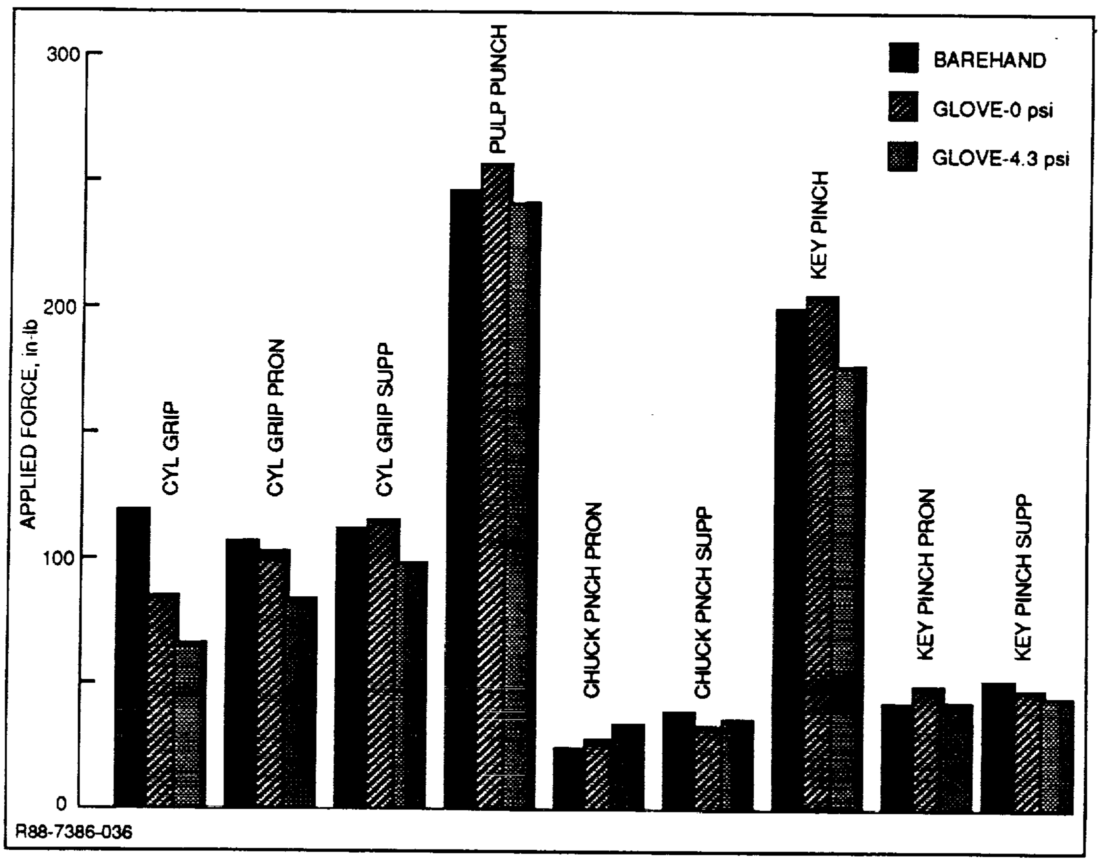

Fig. 5-1 Average Strength Measurement

5.4 TACTILE PERCEPTION

5.4.1 Two-Point Discrimination

The Two-Point Discrimination test evaluated the effect of glove condition on the discrimination of one or two points and on the gap width at which two points were perceived. Ten trials were run and the data on gap width were averaged for analysis.

The effect of hand size was analyzed by correlating it with the gap width at which two points were perceived for each glove condition. Table 5-5 contains these correlations. While none reached statistical significance it was interesting to note that all correlations were positive and increased across glove condition. In the glove/4.3 psid condition there was a stronger relationship within hand size than in the barehand condition and the relationship is one in which subjects with larger hands generally detected two points at greater gap width than subjects with smaller hands. However, since none of these relationships achieved statistical significance the hand size factor was not analyzed further.

Table 5-5 Correlations of Hand Size with Two-point Discrimination

Glove Condition		
Barehand	Glove-0 psid	Glove-4.3 psid
-.21	-.31	-.47

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Table 5-6 presents the frequencies with which subjects correctly reported the presence of a gap or no gap and the frequencies of errors. In the barehand condition a total of three errors out of 100 trials were made compared with 9 in the glove/0 psid and 13 in the glove/4.3 psid conditions. While the total number of errors was small, the percentage increase across conditions was quite large, indicating greater task difficulty in the gloved hand conditions.

Table 5-7 presents the average gap width reported as a function of glove condition. Figure 5-2 presents these data graphically. As can be seen in the table and figure there was a large increase in the width at which two points were detected

Table 5-6 Frequency of Correct & False Responses on Two-point Discrimination Test

Response / Test Cond.	Glove Condition					
	Barehand		Glove-0 psid		Glove-4.3 psid	
	No Gap	Gap	Gap	No Gap	Gap	No Gap
Gap	0	70	67	3	62	8
No Gap	27	3	6	24	5	25

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Table 5-7 Two-point Perception Gap Width (in) as a Function of Glove Condition

Glove Condition		
Barehand	Glove-0 psid	Glove- 4.3 psid
.08 (.02)	.19 (.06)	.23 (.07)

Table values are expressed in means; standard deviations are in parentheses.

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in the unpressurized glove condition when compared with the barehand. The unpressurized glove width was nearly 2.5 times as great as the barehand. In the pressurized glove condition two points were perceived at nearly 3 times that of the barehand. The change in perception associated with the pressure alone, therefore, was relatively small compared with the change associated with the glove itself.

It is interesting to note that the use of the "V-Test" methodology is partially validated by comparing the barehand two-point threshold of these data to the two-point threshold of the classic aestheometer methodology. Weber(25) reported that the two-point threshold for the fingertip was 0.09 in. This compares very favorably with the barehand threshold of 0.08 in. found in our data.

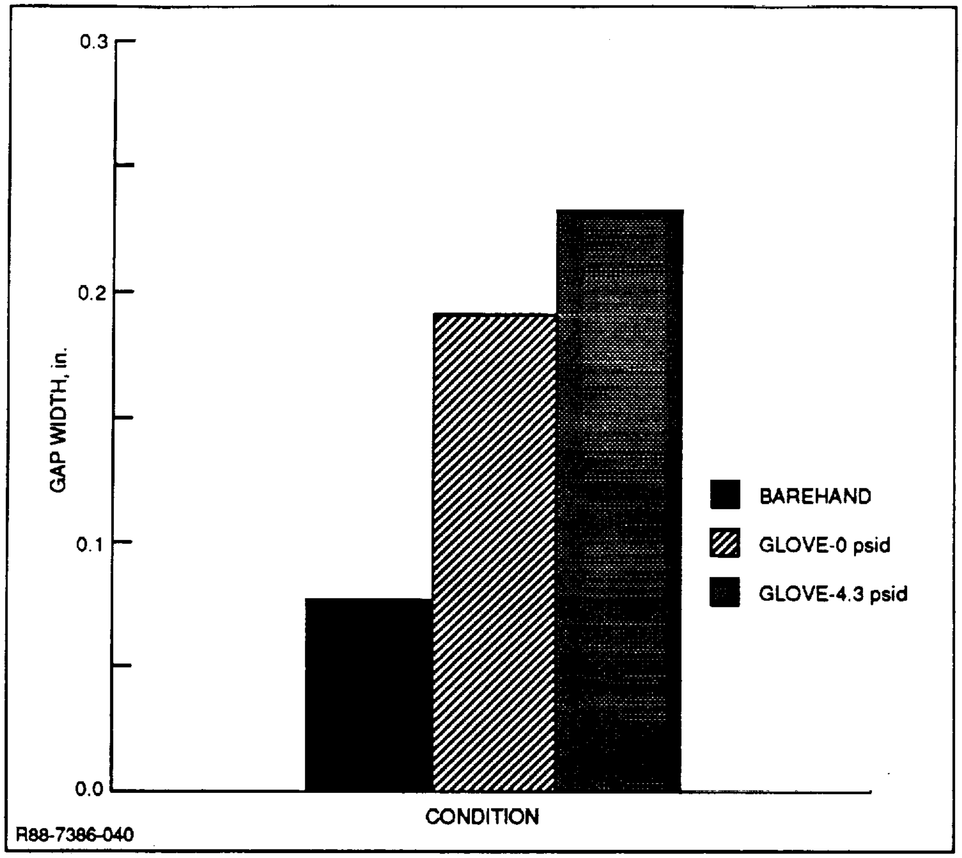

Fig. 5-2 Average Perceived Gap Width

5.4.2 Object Identification

The object recognition test evaluated subjects ability to discriminate between objects as a function of their shape and size, and glove condition. The data collected were size and shape judgements which were converted to frequencies of correct responses and percent correct. In addition, time to respond was recorded. These two dependent variables will be treated separately.

Size & Shape Judgements

The effect of hand size was analyzed by correlating it with the overall percent correct judgements for each subject as a function of glove condition.

Table 5-8 presents the correlation between hand size and percent correct recognition as a function of glove condition. None of these correlations was significant so the hand size variable was not considered further in the data analysis of recognition response.

Table 5-8 Correlation of Hand Size with Object Identification Frequency of Correct Response

Glove Condition		
Barehand	Glove-0 psid	Glove-4.3 psid
-0.17	0.47	-0.07

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Table 5-9 presents the average percent correct and frequency of correct response as a function of glove condition, object size, and object shape. To simplify the interpretation of the data, Tables 5-10 and 5-11 present the same data for shape and size separated respectively and Fig. 5-3 and 5-4 present these data graphically. With respect to shape identification, the major factor was glove condition. The overall percentage of correct identification differed little across the four shapes, 90%, 86%, 86%, and 87% for the sphere, cube, cylinder, and rectangle, respectively. In the bare hand condition subjects were correct on 97.5% of their judgements. The only errors were mistaking a rectangle for a cube. There was little difference between the glove with and without pressure, 85% and 80% correct respectively. The errors made were considerably more varied indicating much

Table 5-9 Object Identification: Frequency of Correct Responses

Object	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Small Sphere	100	80	100
Medium Sphere	70	80	60
Large Sphere	40	20	40
Small Cube	90	90	70
Medium Cube	80	66	70
Large Cube	70	70	50
Small Cylinder	90	60	80
Medium Cylinder	90	66	50
Large Cylinder	90	60	70
Small Rectangle	100	60	60
Medium Rectangle	90	70	90
Large Rectangle	100	70	70

Table values are expressed in percent.

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Table 5-10 Object Identification: Frequency of Response as a Function of Shape

Barehand		Sphere	Cube	Cylinder	Rectangle	Percent Correct
Stimulus	Sphere	30	-	-	-	100
	Cube	-	27	-	3	90
	Cylinder	-	-	30	-	100
	Rectangle	-	-	-	30	100
Glove-0 psid						
Stimulus	Sphere	25	2	3	-	83
	Cube*	-	25	1	3	86
	Cylinder	1	1	22	6	73
	Rectangle	-	5	1	24	80
Glove-4.3 psid						
Stimulus	Sphere	26	1	3	-	87
	Cube	1	25	1	3	83
	Cylinder	-	-	26	4	87
	Rectangle	-	3	2	25	83

* Subject No. 234 was not presented with medium cube in the 0 psid glove condition.

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greater trouble discriminating the curved surfaces from the edges. The most frequent errors were:

- Mistaking a sphere for a cylinder
- Mistaking a cube for a rectangle
- Mistaking a cylinder for a rectangle
- Mistaking a rectangle for a cube.

Table 5-11 and Fig. 5-4 show the recognition data for size. The differences between the glove conditions was not as great as the difference between the sizes themselves. Subjects were correct at judging size 86% barehanded while the percentage correct dropped to 79% in both of the gloved hand conditions. However

Table 5-11 Object Identification: Frequency of Response as a Function of Size

Barehand		Response: Small	Response: Medium	Response: Large	Percent Correct
Stimulus	Small	39	1	-	98
	Medium	5	33	2	83
	Large	-	9	31	78
Glove-0 psid					
Stimulus	Small	38	2	-	95
	Medium*	9	30	-	77
	Large	-	14	26	65
Glove-4.3 psid					
Stimulus	Small	36	4	-	90
	Medium	6	34	-	85
	Large	-	15	25	63

* Subject No. 234 was not presented with medium cube in the 0 psid glove condition.

MR88-7386-044

the differences between sizes were great. Small objects were correctly identified as small 94% of the time. Medium objects were correctly identified as medium 81% of the time and large objects were correctly identified as large 69% of the time. Taken together these data indicate a bias towards judging objects as smaller than they were especially in the gloved hand condition. Subjects seldom mistakenly judged an object as larger than it was. This was probably due to a loss of tactility in the gloved hand thus making objects harder to feel and harder to identify, hence they were judged as smaller than they really were.

Table 5-12 presents the average correlation between hand size and object recognition time as a function of glove condition. None of the correlations were significant although there was an increase in magnitude across the glove conditions.

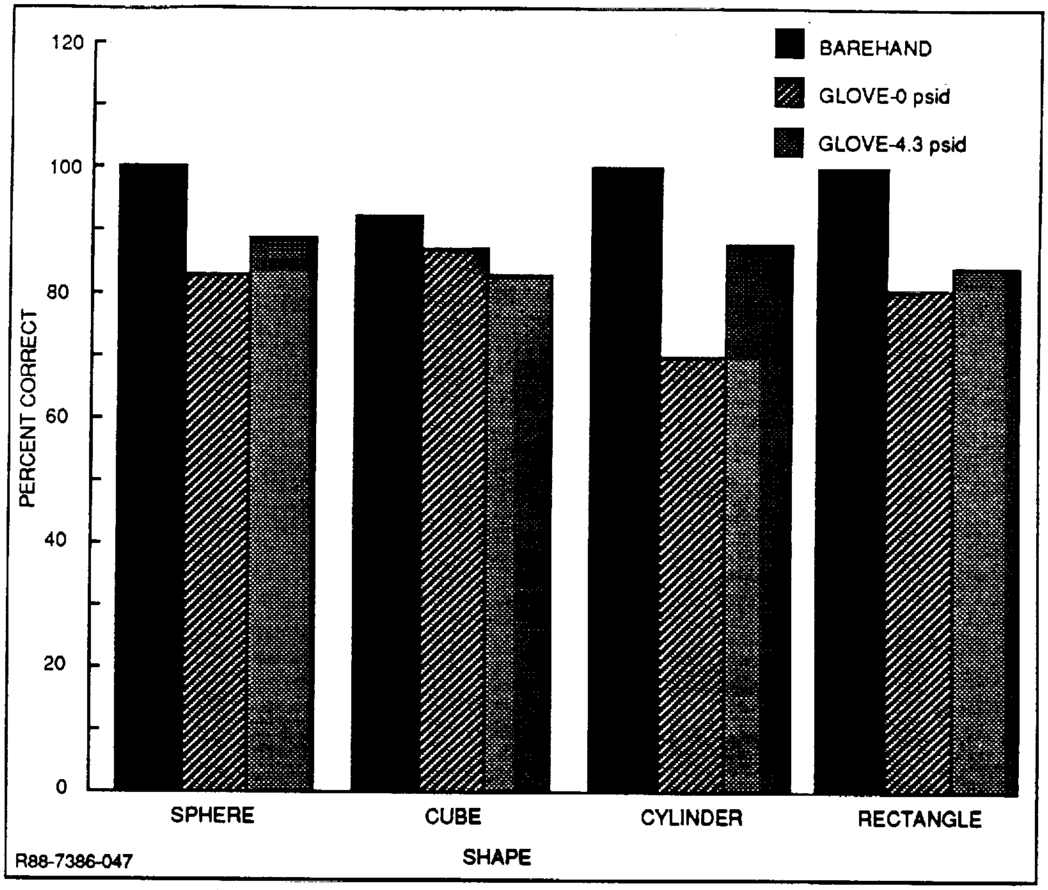

Fig. 5-3 Percent of Objects Correctly Identified by Shape

Table 5-13 presents the average time to recognize objects as a function of their size and shape and glove condition. The average recognition time for the bare hand was 2.5 seconds. In the glove-0 psid condition the average recognition time was 6.5 seconds (260% above bare hand) and in the pressurized glove 7.28 seconds (291% above bare hand). The most significant factor, therefore, was the glove itself and the pressure increment had only a small effect on performance.

There were also small differences between objects shapes and sizes. The average recognition times for the sphere, cube, cylinder and rectangle were 4.35, 4.99, 5.8, and 6.62 seconds, respectively. Average times for small, medium, and large objects was 4.65, 6.07, and 5.44 seconds, respectively.

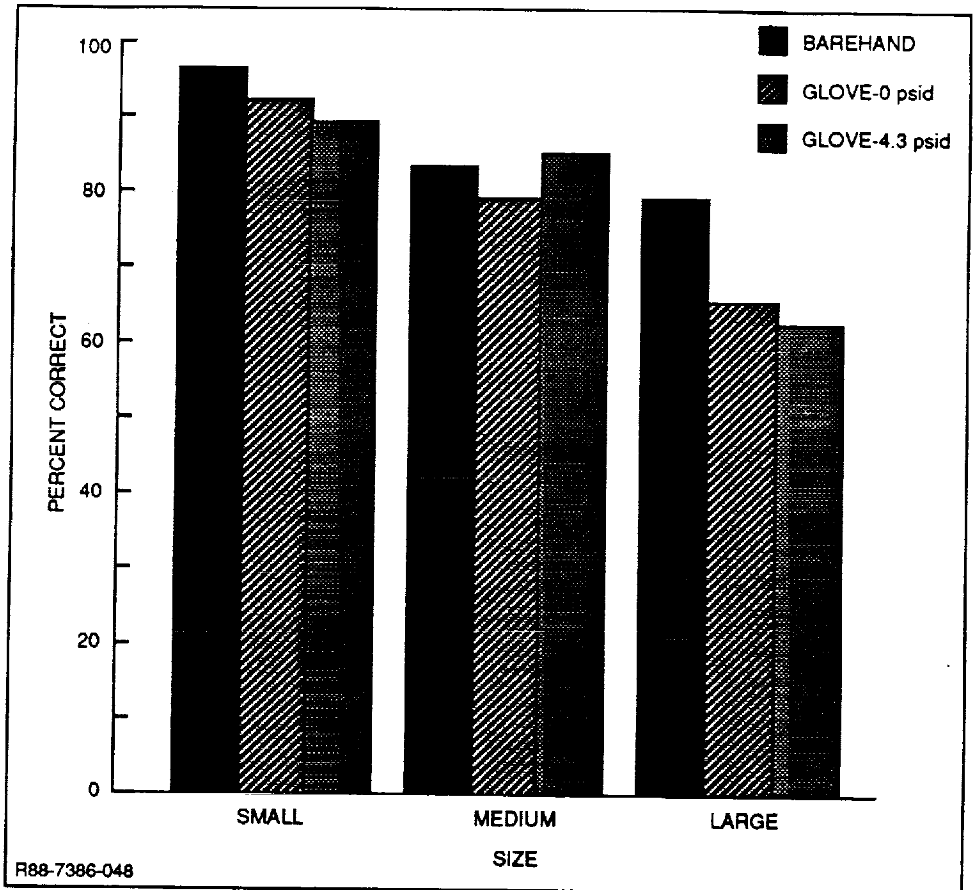

Fig. 5-4 Percent of Objects Correctly Identified by Size

Table 5-12 Correlation of Hand Size with Recognition Time

Glove Condition		
Barehand	**Glove-0 psid**	**Glove-4.3 psid**
-0.2	-0.19	-0.43

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5.4.3 Precision Grip Force Control

The precision grip force control test evaluated the effect of glove condition, grip type, weight lifted, and fixture handle type on grip force safety margin.

Table 5-13 Average Object Identification Time, sec

Object	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Small Sphere	2.40 (1.51)	4.90 (4.09)	5.10 (3.14)
Medium Sphere	2.60 (1.40)	5.40 (5.50)	4.50 (2.35)
Large Sphere	4.50 (2.34)	4.00 (2.83)	5.75 (1.26)
Small Cube	2.00 (0.50)	3.44 (1.94)	4.00 (1.53)
Medium Cube	2.63 (1.77)	7.50 (5.75)	7.71 (3.90)
Large Cube	2.20 (0.91)	5.43 (2.07)	10.00 (6.00)
Small Cylinder	1.89 (0.78)	5.83 (3.31)	7.13 (4.39)
Medium Cylinder	3.40 (1.67)	7.67 (5.82)	8.60 (1.14)
Large Cylinder	1.72 (0.67)	10.33 (5.54)	5.86 (2.85)
Small Rectangle	2.20 (0.63)	9.00 (6.96)	8.00 (6.03)
Medium Rectangle	2.78 (0.97)	7.43 (3.69)	12.67(10.80)
Large Rectangle	1.80 (0.63)	7.57 (5.16)	8.14 (6.39)

Table values are expressed in means; standard deviations are in parentheses.
MR88-7386-046

Safety margin was defined as follows:

- Safety Margin = holding force - slip force.

The effect of hand size was analyzed by correlating it with safety margin for each grip type employed. Table 5-14 presents the correlation between hand size and safety margin as a function of glove condition and grip type. In general there was a fairly strong relationship between hand size and safety margin in the finger grip condition. Of the three correlations, the relationship was significant in the bare hand condition. The +0.73 correlation indicated that the safety margin was larger

Table 5-14 Correlation of Hand Size with Grip/Slip Safety Margin

Rope Size	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Finger	0.73*	0.4	0.57
Palm	0.54	0.41	0.1

* Correlation is significant at the p>.05 level; critical r=0.63 (df=8).
MR88-7386-049

for the subjects with the larger hands. While not significant for the unpressurized glove and glove-4.3 psid conditions the relationship was never-the-less strong. A larger spread of correlations was found for the palm grip. In the bare hand condition, the correlation was 0.54 indicating a strong relationship. In the pressurized glove condition the correlation dropped to 0.10 indicating very little relationship. Averaged over grip types, it appeared that the relationship between hand size and grip type was reduced in the gloved hand condition. Since most of these correlations were not significant the data represent trends only.

Table 5-15 presents the average safety margin as a function of all the test variables. These data are presented graphically in Fig. 5-5 through 5-7.

In an effort to simplify data, the data in the figure were collapsed across the handle type variable. This was done based upon preliminary analysis which indicated that this variable did not have a strong effect on safety margin.

A strong effect of glove condition was found. The average barehand safety margin was 9.37 lb. In the unpressurized glove condition the safety margin increased by 86% to 17.43 lb. In the pressurized glove condition, the safety margin increased an additional 25% to 19.80 lb. Thus it appeared that the glove itself was the major contributor to the increased safety margin. Of the difference between the barehand and the pressurized glove (111%) approximately 78% can be attributed to the glove itself and 22% to the incremental effect of pressure.

Table 5-15 Average Grip/Slip Safety Margin, (lbs)

Handle Type	Weight (lbf)	Grip Type	Glove Condition		
			Barehand	Glove-0 psid	Glove-4.3 psid
Smooth	1	Fingertip	6.13 (5.46)	14.27 (7.18)	16.06 (6.68)
		Palm	9.74 (7.05)	16.84 (7.40)	24.63 (10.08)
	3	Fingertip	9.81 (6.07)	17.46 (9.46)	18.15 (5.75)
		Palm	16.78 (10.98)	22.67 (8.82)	28.61 (9.22)
Coarse	1	Fingertip	3.91 (3.12)	12.59 (7.93)	14.05 (7.08)
		Palm	9.83 (6.30)	19.93 (11.96)	19.59 (10.95)
	3	Fingertip	6.02 (4.00)	13.33 (9.17)	16.18 (7.36)
		Palm	12.74 (7.88)	22.36 (9.35)	21.14 (9.54)

Table values are expressed in means; standard deviations are in parentheses.

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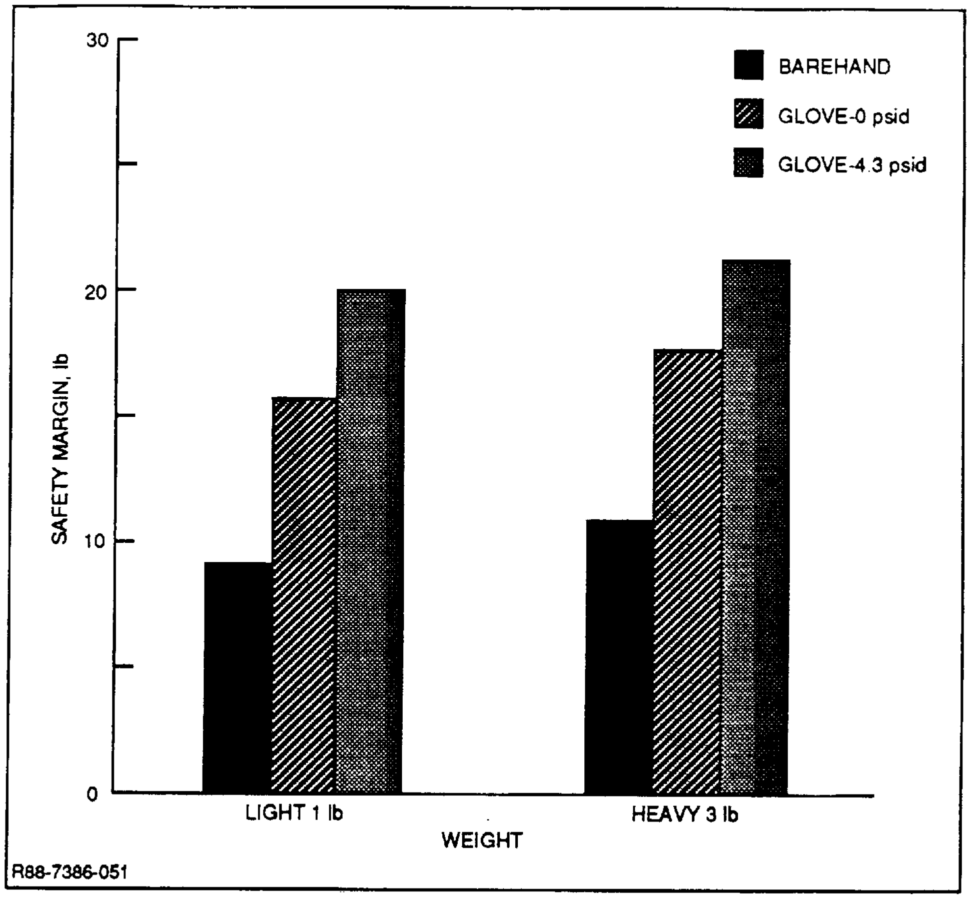

Fig. 5-5 Average Safety Margin Force as a Function of Weight Lifted

The next most significant factor was grip type. The average safety margin for the finger grip was 12.33 lb while the average safety margin for the palm grip was 18.73. This was expected in the barehand due to the greater tactile sensitivity in the fingers when compared with the palm, but it is interesting to note that the difference was fairly constant across all three glove conditions.

A greater safety margin was observed in the 3 lb weight condition (17.10 lb) than the 1 lb condition (13.86 lb) although the difference was not great. The final test variable was handle type. The safety margin for the two handles differed only slightly: 16.76 lb for the smooth handle and 14.31 for the course handle.

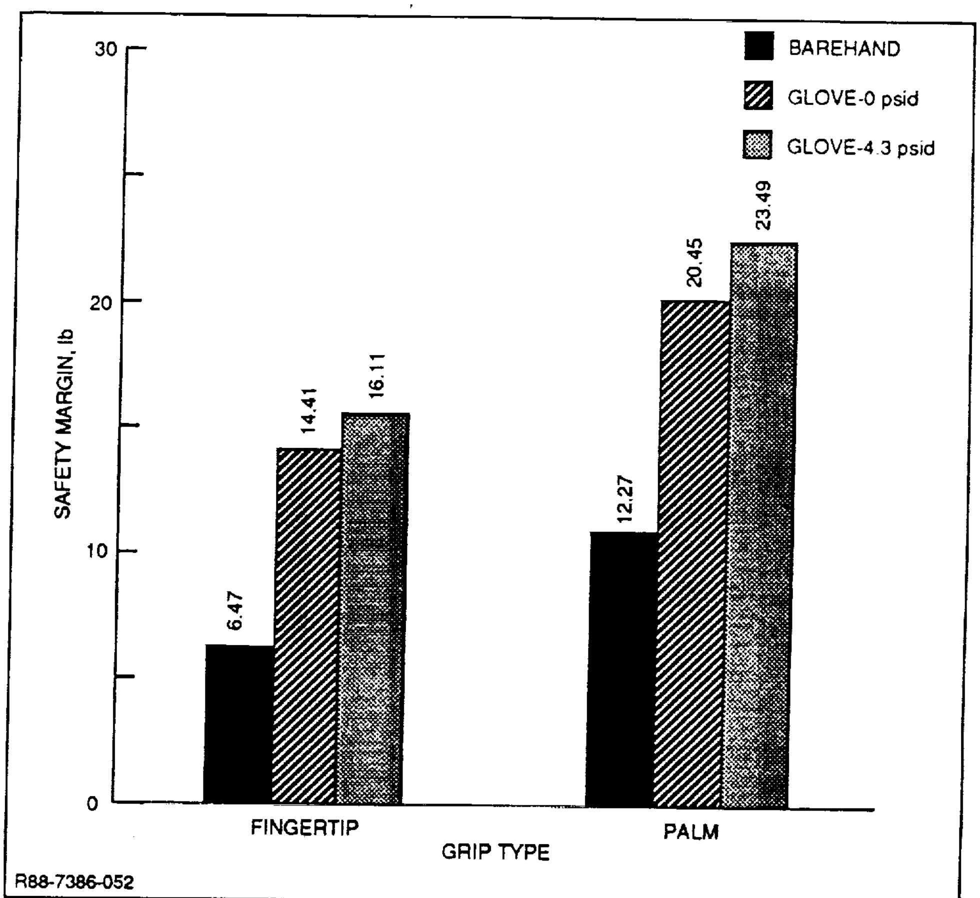

Fig. 5-6 Average Safety Margin Force as a Function of Grip Type

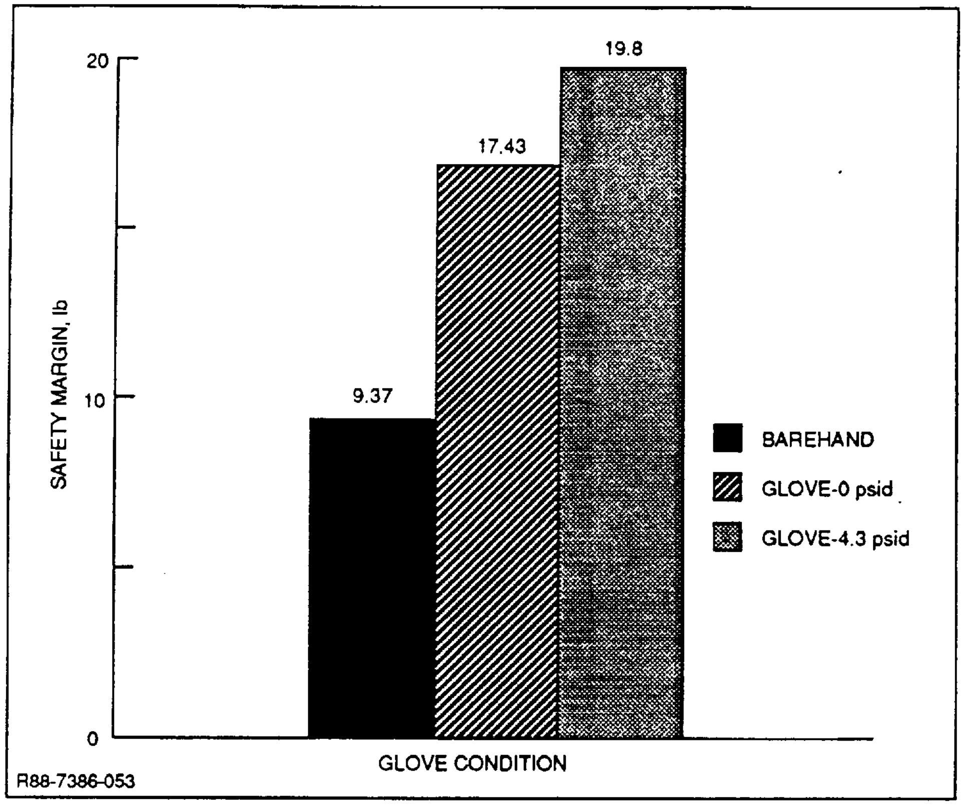

Fig. 5-7 Average Safety Margin Force as a Function of Glove Condition

5.5 DEXTERITY

5.5.1 Pegboard Test Performance

The pegboard test evaluated the effect of glove condition and peg size on the number of pegs inserted in 30 seconds and the number of pegs dropped. Two trials in each condition were run and the data were averaged over these trials for analysis.

The effect of hand size was analyzed by correlating it with the average number of pegs inserted in each glove condition/peg size combination. Table 5-16 contains these correlations. No correlations were calculated for the number of pegs dropped because of the infrequency with which this occurred. A significant positive correlation was found for the glove/4.3 psid condition while handling the small peg indicating that the larger hand size had more insertions. Other than this correlation, the other correlates were insignificant and no consistent trend was observed. The hand size factor was not considered further.

Table 5-16 Correlations of Hand Size with Average Pegs Inserted

Peg Size	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Small (3/16")	.02	.34	.66*
Medium (5/16")	.19	.26	.10
Large (7/16")	.42	.40	.07

* Correlation is significant at the p>.05 level; critical r=.63 (df=8).

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Table 5-17 presents the average number of peg insertions as a function of glove condition and peg size. These relationships are presented graphically in Fig. 5-8. These data show a clear and consistent pattern indicating that both a glove effect and a pressure effect are evident. It is interesting to note that the relationships remain fairly constant across peg sizes. Except for a slight improvement in performance with increasing peg size for the unpressurized glove condition, performance is quite consistent across peg sizes (see Fig. 5-8).

Table 5-17 Average Peg Insertions Per Trail

Peg Size	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Small (3/16")	23.35 (3.37)	11.05 (3.15)	4.40 (1.15)
Medium (5/16")	23.05 (3.88)	13.30 (4.86)	5.10 (2.57)
Large (7/16")	22.95 (4.71)	14.55 (5.61)	5.55 (2.25)

Table values are expressed in means; standard deviations are in parentheses.

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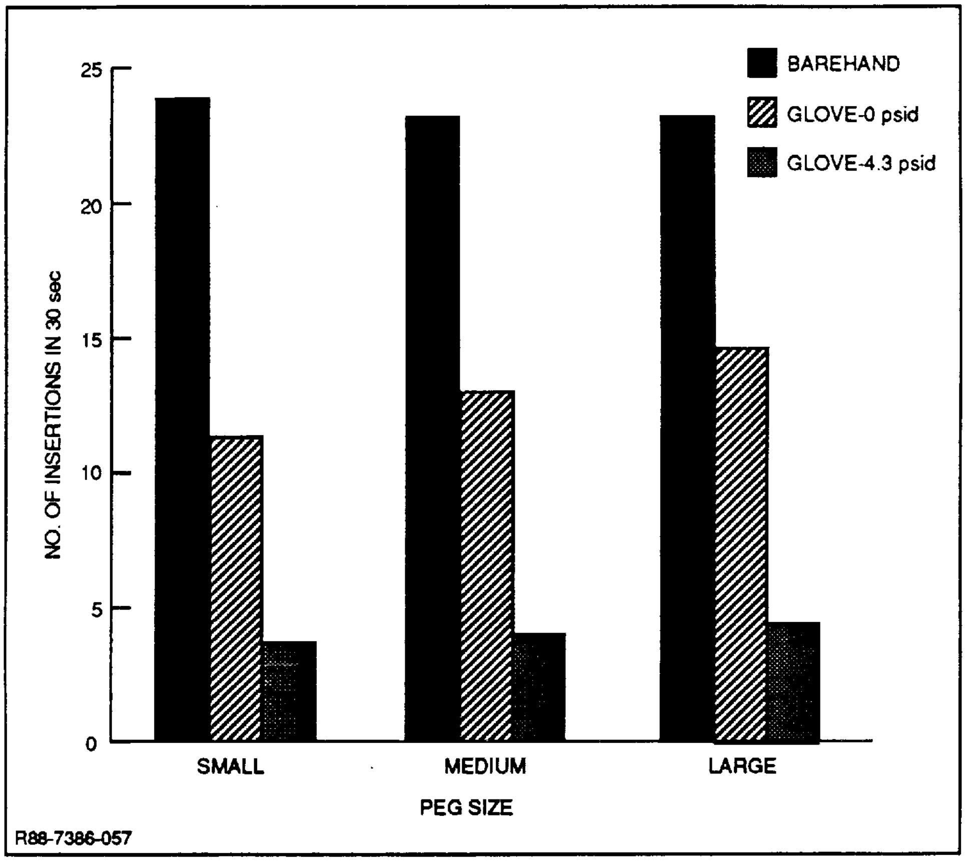

Fig. 5-8 Average Number of Peg Insertions

With respect to glove condition effect, the unpressurized glove reduced dexterity by 44% to 56% of barehand capability. Pressurizing the glove reduced performance another 35% to 21% of barehand capability. This indicates that loss of dexterity was great and that both the glove and the pressure contributed to the degradation of performance. This finding was also consistent across peg sizes.

Table 5-18 provides the average number of pegs dropped per trial as a function of glove condition and peg size. Figure 5-9 presents these data graphically. Few pegs were dropped during these tests. The overall number of pegs dropped was the same for the barehand and unpressurized condition but was slightly higher for the pressurized condition. The latter would have contributed to the poorer performance on peg insertion observed in the pressurized glove condition.

Table 5-18 Average Number of Pegs Dropped Per Trail

Peg Size	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Small (3/16")	0.05 (0.16)	0.05 (0.16)	0.15 (0.24)
Medium (5/16")	0 ( )	0.05 (0.16)	0.15 (0.34)
Large (7/16")	0.10 (0.21)	0.05 (0.16)	0.05 (0.16)

Table values are expressed in means; standard deviations are in parentheses.
MR88-7386-056

5.5.2 Nut & Bolt Assembly Performance

The nut and bolt assembly task evaluated the effect of glove condition and assembly size on the number of assemblies accomplished in 30 seconds and the number of nuts and bolts dropped. Two trials in each condition were run and the data were averaged across these trials for analysis.

Table 5-19 and Table 5-20 show the correlations of hand size with number of assemblies and drops, respectively. Each table provides the correlations as a function of glove condition and assembly size. With respect to assembly time two of the nine correlations were statistically significant. In both cases, unpressurized glove/large nut and bolt assembly and pressurized glove/small nut and bolt assembly, the correlation was positive indicating that more assemblies were made by larger handed people. Overall no clear trends in the pattern of correlations are evident. None of the correlations of hand size with drops were significant. Since

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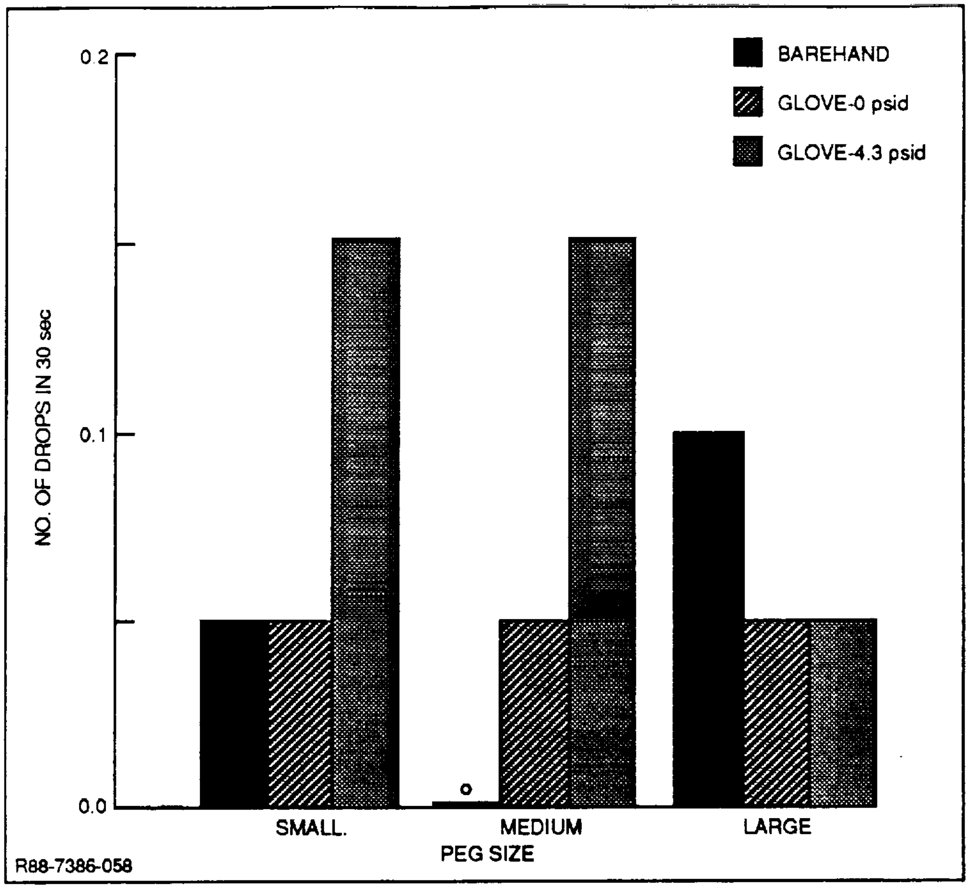

Fig. 5-9 Average Number of Peg Drops

Table 5-19 Correlations of Hand Size with Average Nut & Bolt Assembly Time

Assembly Size	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Small (5/16")	.25	.39	.71*
Medium (1/2")	.32	.41	.35
Large (5/8")	.62	.71*	.26

* Correlation is significant at the p>.05 level; critical r=.63 (df=8).

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Table 5-20 Correlations of Hand Size with Average Nut & Bolt Drops

Assembly Size	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Small (5/16")	.22	.24	-.20
Medium (1/2")	.44	.20	-.28
Large (5/8")	-.45	-.13	-.29

MR88-7386-060

only 2 of 18 of these correlations were statistically significant, the hand size variable was not analyzed further.

Table 5-21 presents the average number of assemblies completed as a function of glove condition and assembly size. Figure 5-10 presents these data graphically. The data show a large effect of glove condition. The pattern of effects is very similar to that observed in the pegboard test, i.e., both a glove effect and a pressure effect are evident. In the unpressurized glove condition, dexterity performance was reduced by 62% to 38% of barehand dexterity. Pressurizing the glove further reduced performance by another 23% to 15% of barehand performance. Both effects were quite large. Size of the assembly was not a strong factor but there were differences. Fewer assemblies were completed with the small nuts and bolts but overall there was little difference between the medium and large sizes.

Table 5-21 Average Number of Nut & Bolt Assemblies Per Trial

Assembly Size	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Small (5/16")	6.38 (1.34)	1.78 (0.82)	0.83 (0.72)
Medium (1/2")	8.13 (1.76)	3.50 (1.49)	1.10 (0.67)
Large (5/8")	7.30 (1.80)	3.10 (1.25)	1.40 (0.62)

Table values are expressed in means; standard deviations are in parentheses.
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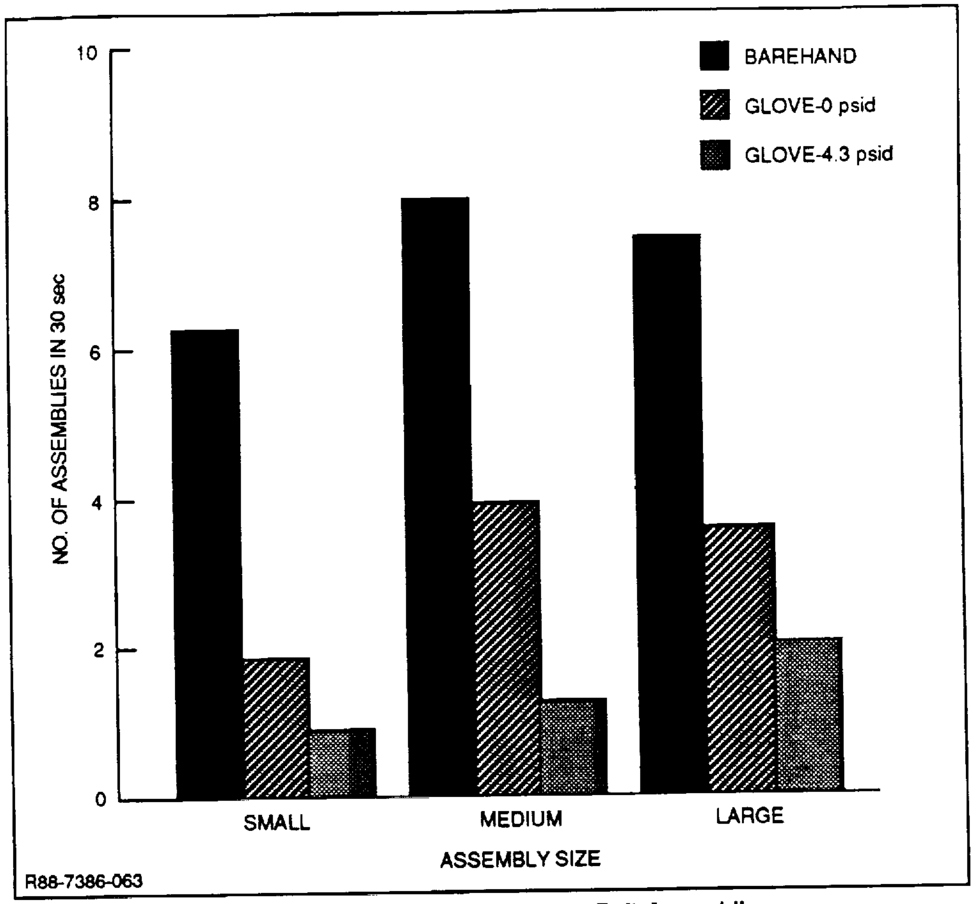

Fig. 5-10 Average Number of Nut & Bolt Assemblies

Table 5-22 presents the number of dropped assemblies as a function of glove condition and assembly size. Figure 5-11 presents these data graphically. Again very strong effects of glove condition were noted. For drops, the effect of the glove was quite a bit stronger than the effect of pressure but both are present. An overall average of 0.33 drops per trial were in the barehand condition while the number more than doubled in the unpressurized glove condition to 0.75. In the pressurized glove condition the number increased to 0.86. These data parallel the results for number of assemblies. Again there was a small effect of assembly size. Fewer drops were committed as the assembly size increased.

Table 5-22 Average Number of Nut & Bolt Drops Per Trial

Assembly Size	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Small (5/16")	0.40 (0.46)	0.90 (0.70)	0.95 (0.69)
Medium (1/2")	0.30 (0.63)	0.65 (0.63)	1.00 (0.67)
Large (5/8")	0.30 (0.42)	0.70 (0.68)	0.65 (0.67)

Table values are expressed in means; standard deviations are in parentheses.
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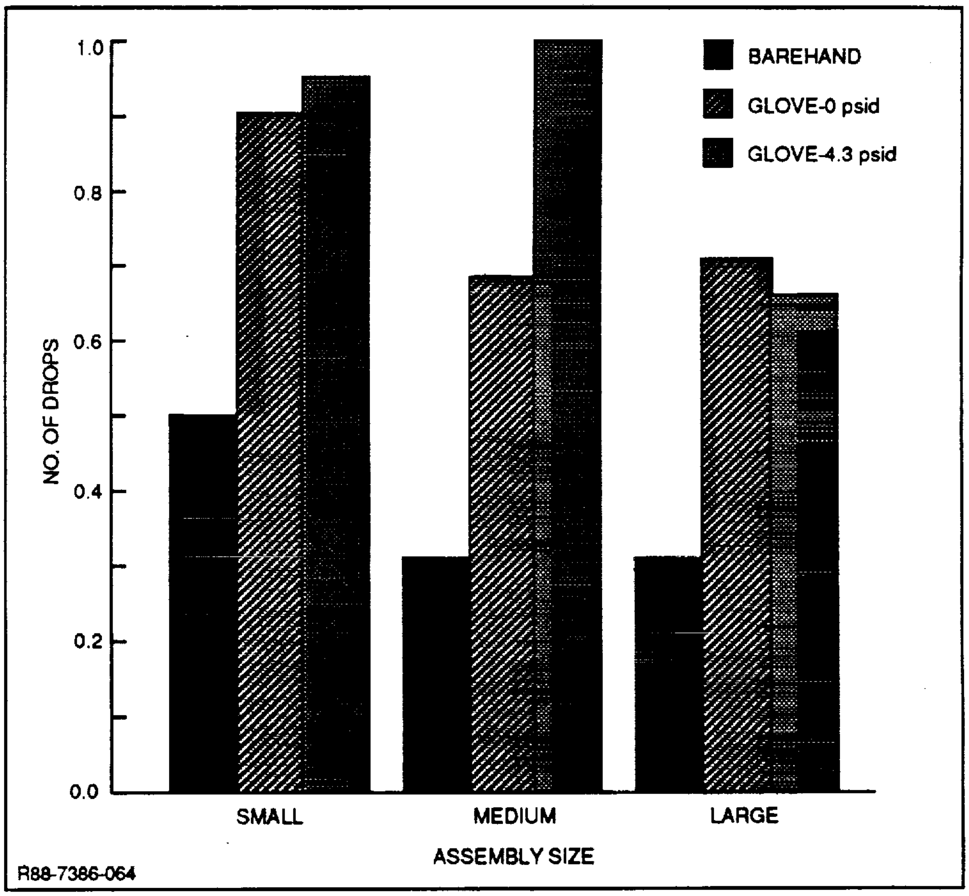

Fig. 5-11 Average Number of Nut & Bolt Drops

5.5.3 Knot Tying Performance

The knot tying test evaluated the effect of glove condition and rope diameter on the time required to tie a knot. Two trials in each condition were completed and then data were averaged for analysis.

The effect of hand size was analyzed by correlating it with time in each of the glove condition/rope diameter combinations. These correlations are presented in Table 5-23. None of these correlations are significant. In general, the correlations for the pressurized glove are stronger than for the other two glove conditions. This indicates a trend toward a relationship where larger handed subjects required greater time to tie the knot. The correlations in the other two conditions are much less and about the same as each other. However, since the relationships were not significant, hand size was not considered in further analysis.

Table 5-23 Correlation of Hand Size with Average Knot Tying Time

Rope Size	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Thin (1/4")	.10	-.36	-.50
Thick (5/8")	-.41	-.19	-.47

MR88-7386-065

Table 5-24 presents the average knot tying times as a function of glove condition and rope diameter. These data are presented graphically in Fig. 5-12. As with the other dexterity measures there was a strong effect of both glove and pressure. The overall barehand average time was 7 seconds. The average time in the unpressurized glove condition was 100% greater (13.85 seconds). In the pressurized glove condition the average time was 400% of barehand (29 seconds). These strong glove and pressure effects can be seen clearly in Fig. 5-12. These data are quite consistent with the other dexterity tests and measures in supporting both a glove effect and an incremental effect of pressure.

Table 5-24 Average Knot Tying Time (sec)

Rope Size	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Thin (1/4')	5.85 (2.02)	15.65 (7.08)	30.70 (10.11)
Thick (5/8")	8.13 (1.03)	12.05 (5.13)	26.65 (14.44)

Table values are expressed in means; standard deviations are in parentheses.
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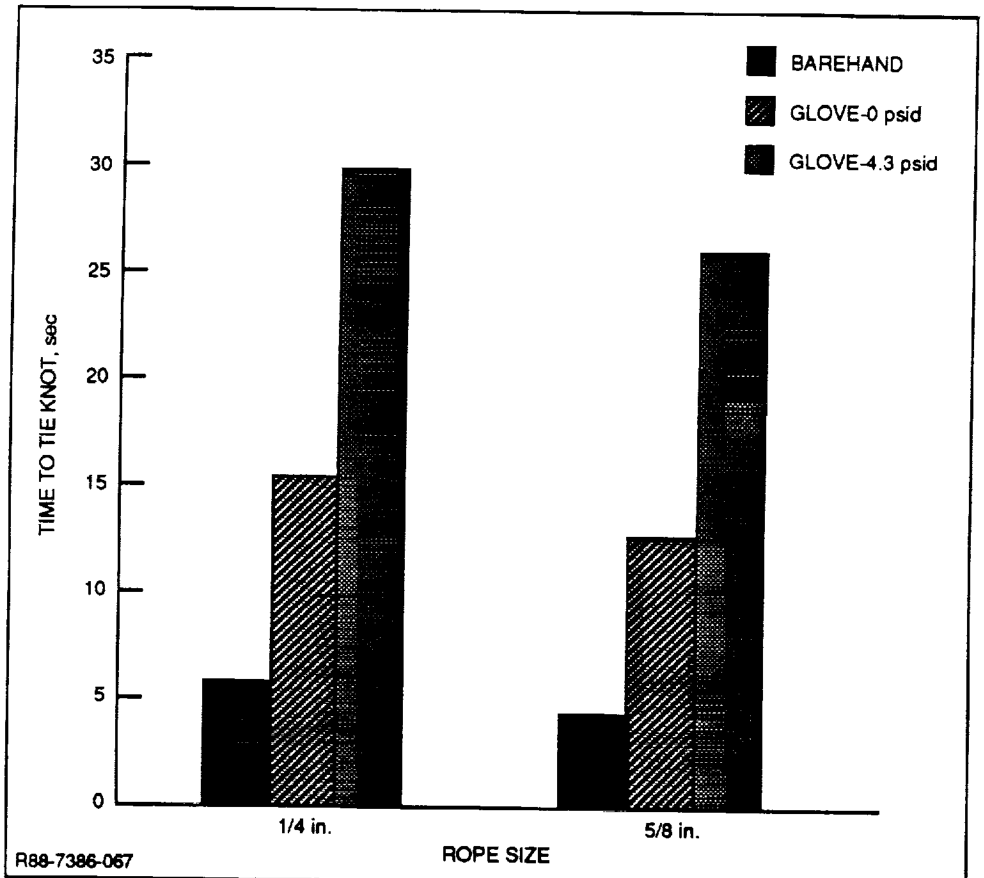

Fig. 5-12 Average Knot Tying Time

Also consistent with other dexterity tests, the effect of object size was small. In this case the average tying time with the thin rope was 17.4 seconds and 15.61 seconds for the thick rope.

5.6 FATIGUE

5.6.1 Physiological Fatigue

Of the four muscles originally planned for EMG measurement, only three were successfully detected. Persistent instrumentation problems with the fourth EMG channel on the dorsal intersseous muscle required the elimination of this muscle from the study. However, it was determined from preliminary measures that this particular muscle was not consistently active during the gripping task, particularly when the EVA glove was being used.

Of the three muscles monitored, the finger flexors and wrist extensors produced consistent findings, whereas the thumb flexor data was more variable for the three test conditions and was therefore of less predictive value. This variability was most likely due to the inconsistent use of this muscle during gripping, fewer successful trials, and problems associated with motion artifact related to glove interference with the electrode. In the analysis, change in median frequency over trials was examined.

The results for these three muscles of the forearm and hand are summarized in Fig. 5-13 to 5-18. The average value of the change in median frequency from its initial value is plotted for each trial. Each figure represents the results for a particular muscle and the groupings for the three different glove conditions are represented by different symbols which are connected by a curve fitting procedure. The following results are categorized according to muscle group.

Finger Flexor Muscle Flexor Digitorium Superficialis:

The results for the finger flexors (see Fig. 5-13) during the dynamic tests demonstrated minimal change in median frequency (i.e., minimal fatigue) for the bare handed condition compared to either glove condition. Specifically, 5 out of 10 subjects showed no fatigue in the barehanded condition for finger flexors, with two of the remaining five subjects showing minimal fatigue (less than 15 Hz decrease in median frequency for all fatigue trials). In contrast, 9 out of 10 subjects showed significant fatigue in the finger flexors for the glove-4.3 psid condition. The results for the glove-0 psid condition demonstrated more fatigue in this condition than in the barehand condition, but less fatigue overall than the glove-4.3 psid condition. This can be seen by comparing the slopes of the three curves in

Fig. 5-13. A more negative slope indicates greater fatigue. Only one subject had less than a 10 Hz decrease in median frequency for the glove-0 psid condition. These changes were moderate, however, with most around 15 Hz. Averaging across the fatigue trials, the barehand change in median frequency increased 457% to -8 Hz and in the glove condition the average change was -15.5 Hz, 827% above barehand. The average values of the maximal change in median frequency during the seven fatigue trials are shown in Fig. 5-14 as a function of glove condition. The maximum

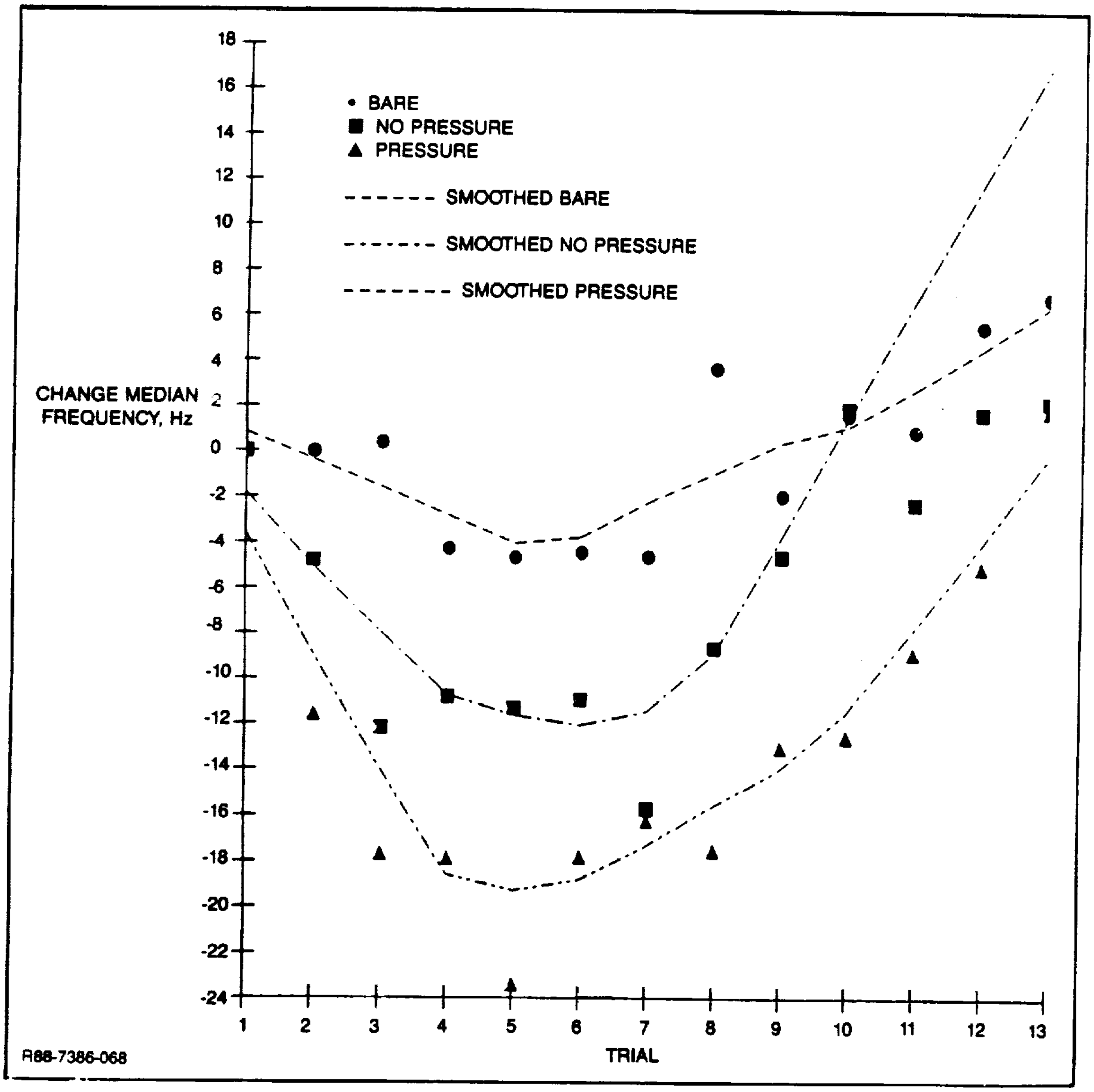

Fig. 5-13 Change in Finger Flexor Median Frequency WRT IMF1

change in median frequency across subjects in the barehand condition was 10.5 Hz. In the unpressurized glove condition the average maximum change increased 175% to 18.4 Hz and in the pressurized glove condition the average maximum change increased to 290% of barehand to 30.5 Hz. These data indicate nearly equal effects of the glove and the pressure. The curves in Fig. 5-13 show a similar pattern. The separation between the curves demonstrates these effects.

In Fig. 5-13 the data from Trials 7-13 summarize the recovery data over all subjects. The recovery data for the finger flexors showed that for the 9 subjects who experienced fatigue in the pressurized glove condition, 5 recovered within 4-5 minutes, three did not recover during the 7 min rest period and one recovered completely at the 1-2 minutes of rest. Those subjects who did not recover by the end of the experiment had the highest changes in median frequency during the dynamic fatigue contractions. Recovery for the subjects who fatigued in the glove-0 psid condition, tended to be complete within two minutes. It should be noted that

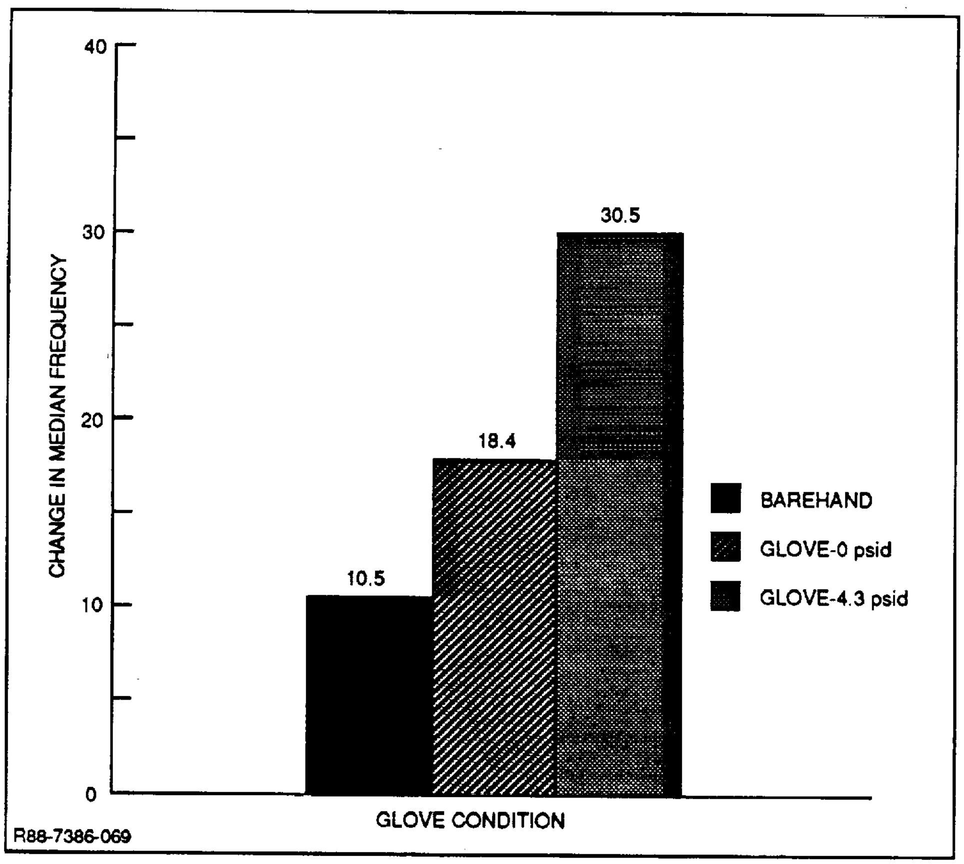

Fig. 5-14 Average Maximum Change in Median Frequency WRT Finger Flexors

these individuals had about half the level of fatigue as in the pressurized glove condition, which might explain why they recovered twice as quickly. Also, in more than a few cases, it was observed that the median frequency values following recovery overshot the baseline value, sometimes by as much as 20-30 Hz.

Wrist Extensor Muscle:

The fatigue data for the wrist extensor muscle (see Fig. 5-15) presented a different fatigue response as a function of glove condition than did finger flexors. A comparison of the slopes of the curves in the figure indicate a nearly opposite

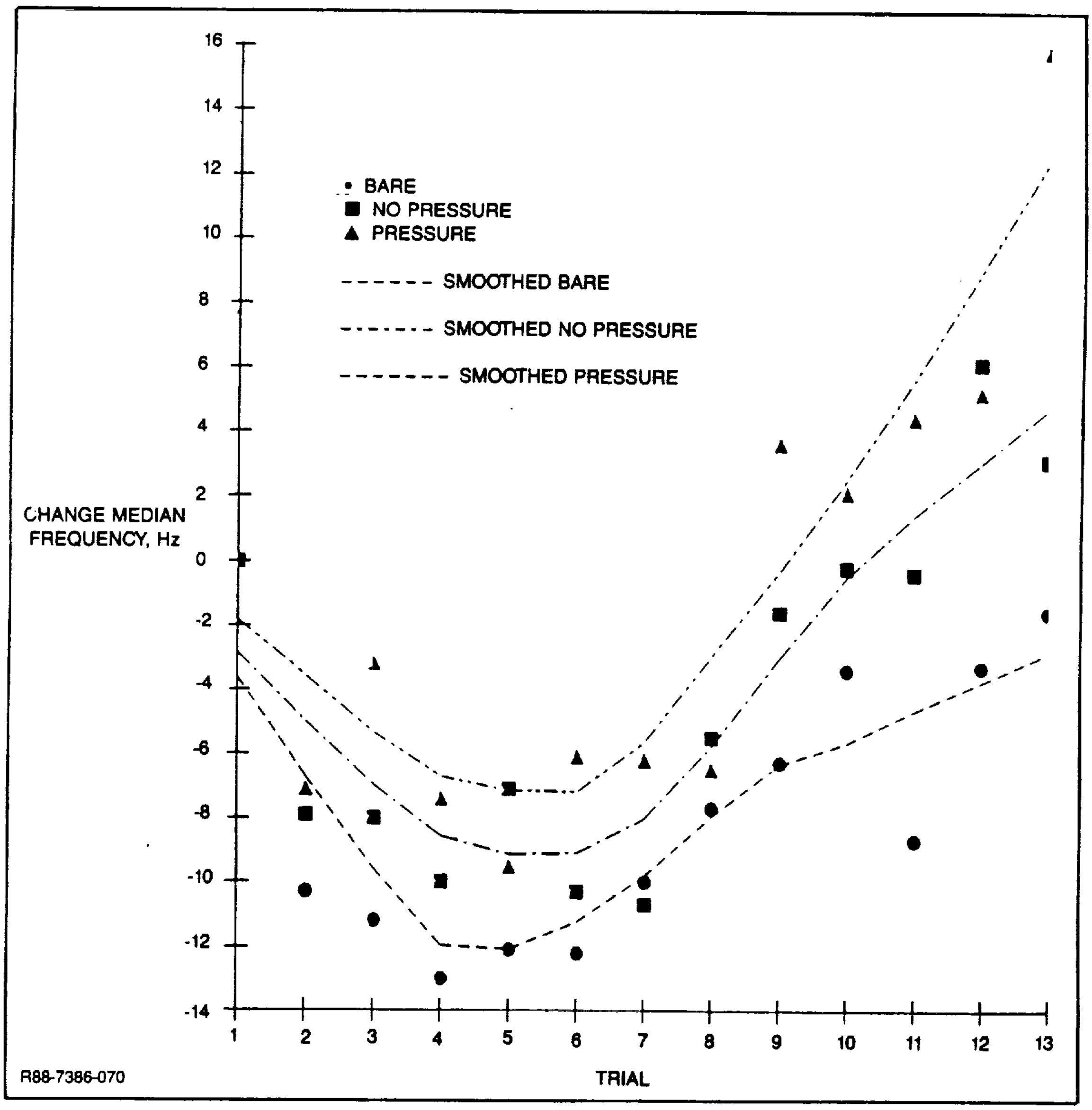

Fig. 5-15 Change in Wrist Extensor Median Frequency WRT IMF1

pattern of results. The barehand condition exhibited the greatest fatigue and the pressure glove condition the least. This is substantiated by comparing the average change in median frequency across trials. The average change in the barehand condition was -10.16 Hz and in the unpressurized glove condition it was -7.5 Hz (73% of barehand) and in the pressurized glove was -5.5 (54% of barehand). The wrist extensor in 6 out of 9 subjects showed fatigue during the barehanded condition. Five of nine subjects showed no fatigue in the glove-4.3 psid condition for wrist extensors whereas all but one subject demonstrated fatigue in the glove-0 psid condition. Recovery was slower in the wrist extensors than in the finger flexors, particularly in the barehanded condition. It still could be seen that recovery was a function of how much overall fatigue was present, i.e., those individuals who had the greatest overall drop in median frequency, took longer to recover. The average values for the maximal change in median frequency during the seven fatigue trials are shown in Fig. 5-16 as a function of glove condition. There was not as great a difference in average maximum change in the wrist extensor as in the finger flexors.

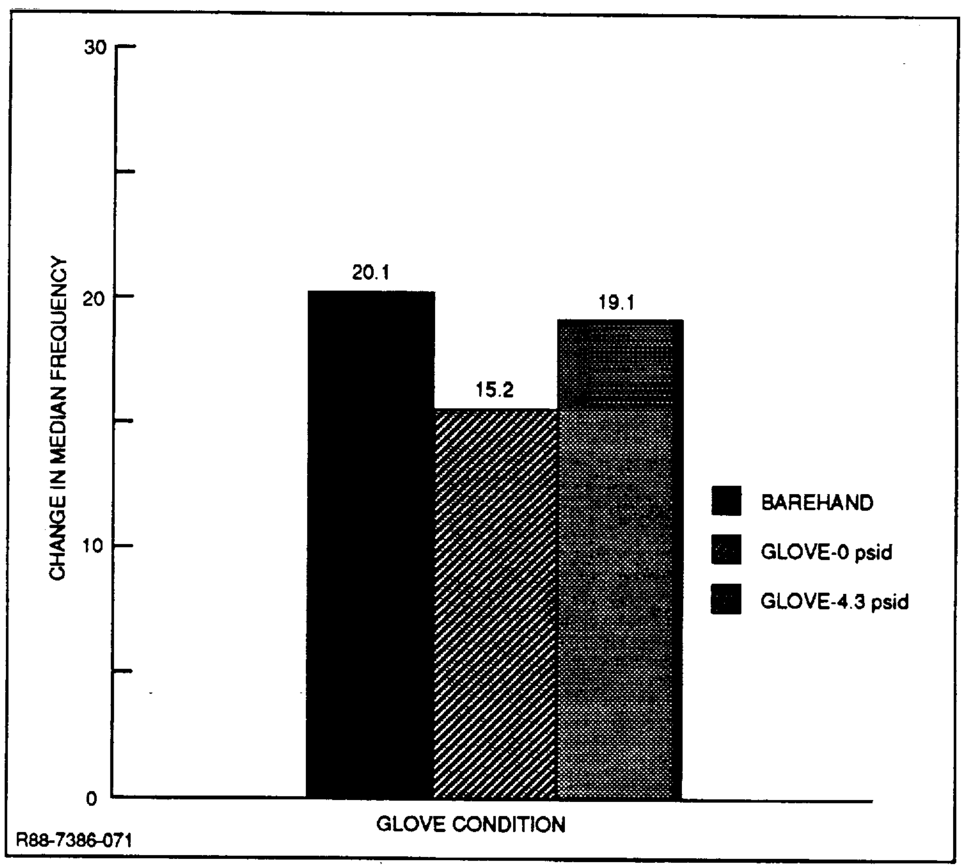

Fig. 5-16 Average Maximum Change in Median Frequency WRT Wrist Extensors

The barehand average maximum change was 20.1 Hz. In the glove-0 psid condition the average maximum change dropped to 76% of barehand to 15.2 Hz. In the pressurized glove the average was 19.1 Hz or 95% of barehand. Thus while fatigue was clearly evident, the pattern of fatigue across the wrist extensor muscle was different.

Thumb Flexor Muscle:

The data for the thumb flexor (see Fig. 5-17) was more problematic than for either the wrist extensor or finger flexor muscles. Five of the ten subjects had data for only one glove condition and there were only three subjects who had data for all three conditions. These difficulties arose from instrumentation problems, difficulties in getting good adhesion of the transducer to this muscle, and the inconsistent use of this muscle during a trial and between subjects. The noise in these data can be seen by the deviations of the trial averages from the curves fit to the data, especially in the glove conditions. Note that the curve for the pressurized glove condition shows a greater degree of fatigue (greater negative change in median frequency) over the fatigue trials than the other two conditions. The individual trial averages reflect the same finding. The barehand and unpressurized glove conditions showed nearly equal curves across the first five trials. On trial six the average for the unpressurized glove drops considerably to almost -20 Hz (see Fig. 5-17). This dramatic effect seems to persist over the next two trials (which were during the recovery period). Thus the curve for the unpressurized glove contains a considerable spike downward around trial 7. The data for the barehand condition generally exhibits less fatigue than the other two conditions. This conclusion is substantiated by the average changes in median frequency across the fatigue trials. In the barehand condition the average change was -5.5 Hz. In the unpressurized glove condition it was increased by 124% to -6.83 Hz and in the pressurized glove condition it was increased to 195% of barehand change to -10.75 Hz. For those experiments in which at least two glove conditions could be measured (only 4 subjects), the results were not consistent across subjects. That is, half the subjects showed significant fatigue for the barehanded condition and the other half did not. In all but one case, the glove-0 psid and glove-4.3 psid conditions were both associated with a significant, and nearly equal amount of fatigue. The recovery to baseline for almost all instances of fatigue was complete within 4 minutes with little differences associated with glove condition. The average maximal change in median frequency for the thumb flexor data for the first seven "fatigue" trials are shown in Fig. 5-18 as a function of glove condition.

The average maximum change in median frequency for the barehand condition was 21.2 Hz. In the unpressurized glove condition the average maximum change dropped to 70% of barehand to 14.8 Hz and in the pressurized glove condition was

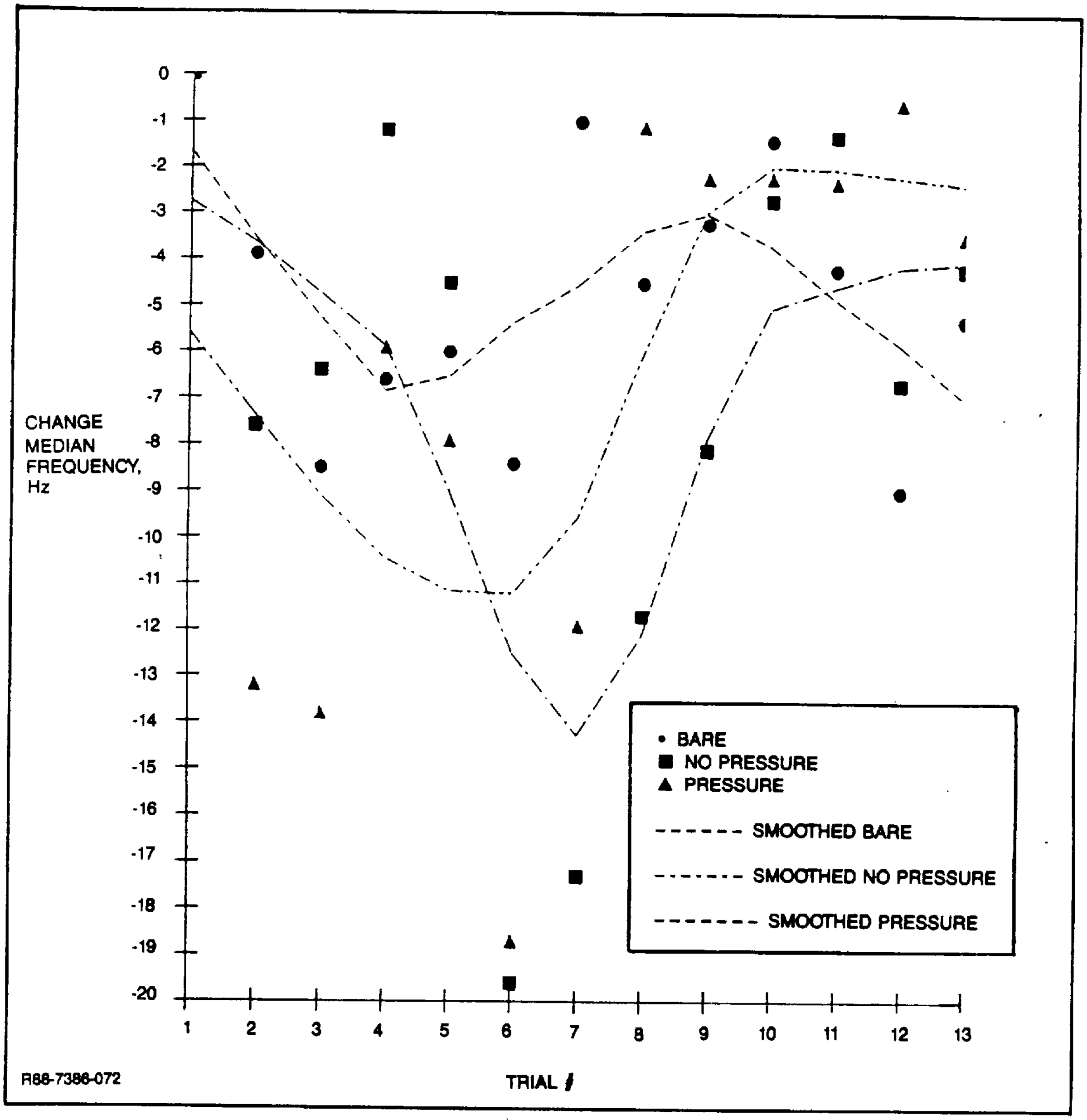

Fig. 5-17 Change in Thunb Flexor Median Frequency WRT IMF1

122% of barehand to 26 Hz. However, these data are probably less reliable than in the other two muscles due to the noisiness of the data. Measures of maximum change become less meaningful when data is highly variable as was the case in these data.

In general, two of the muscles showed similar patterns of fatigue, the finger and thumb flexors, although the latter was considerably more noisy. The barehand condition was associated with the least fatigue and the pressurized glove condition was associated with the greatest fatigue. The unpressurized glove condition was inbetween these two. The results for the wrist extensor showed the opposite result. The pressure glove condition actually helped to inhibit the pressure of fatigue in the wrist extensor muscles. Thus fatigue was successfully measured using the quantitative EMG procedure and analysis approach. The different patterns of fatigue across muscles probably reflects different use of muscles when the subject performed the

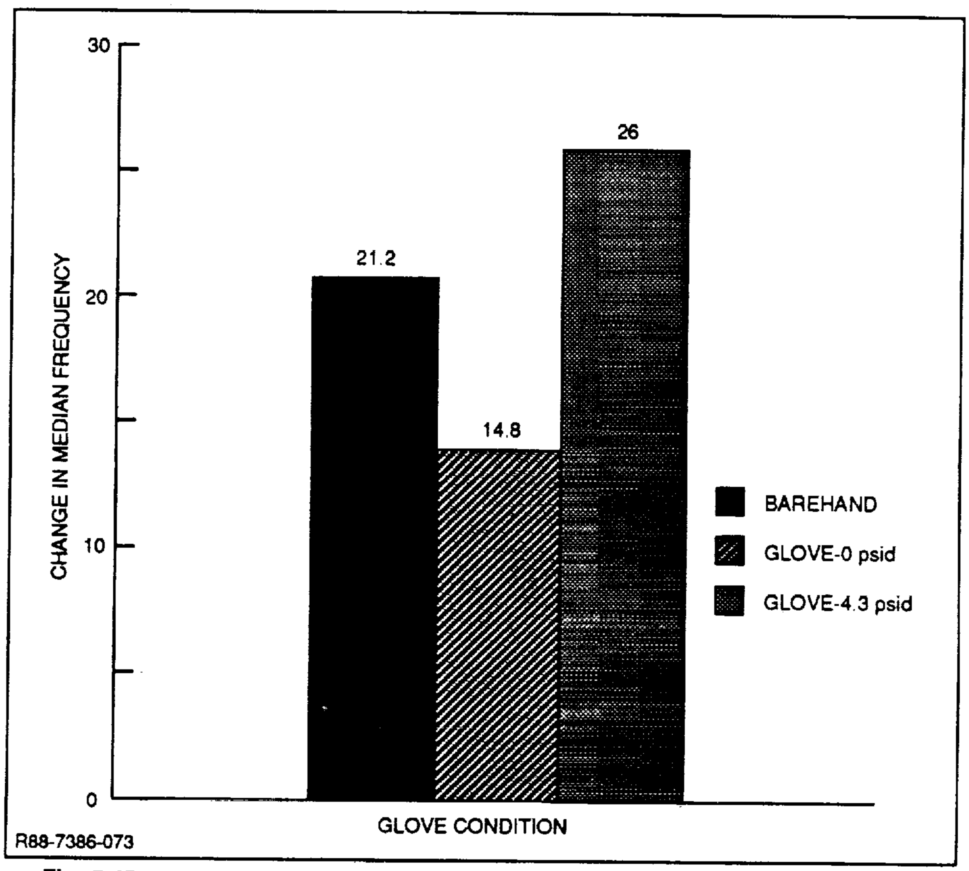

Fig. 5-18 Average Maximum Change in Median Frequency WRT Thumb Flexors

task barehanded compared with the glove conditions. This finding is interesting in that it suggests that the pattern of loading on muscle changes as a function of glove conditions. This finding is clearly worth future investigation. Furthermore, since fatigue is glove conditions dependent, future studies should analyze the effect of different tasks as well.

5.6.2 Subjective Fatigue

Subjective fatigue was evaluated in two ways. First, a subjective rating on a five-point scale (see Table 4-5) was obtained at the end of each fatigue test trial. Thus the ratings were in real-time with respect to the ongoing protocol. Second, following the fatigue test (Post hoc) in each condition the subject rated their overall fatigue and its relationship to task performance on a nine-point scale (see Fig. 4-18).

Real-Time Fatigue Ratings

Table 5-25 contains the average fatigue ratings collected during the fatigue protocol as a function of Glove Condition and Trial. Figure 5-19 presents this data in graphic form. While the ratings at Trial 1 were approximately equal for all three glove conditions the increase in slope is greater for the glove 0 psid condition and even greater for the pressurized glove condition. By trial 7 (the end of the fatigue portion of the protocol), the subjects rated the unpressurized glove as 23% more fatiguing than the barehand and the pressurized glove as 44% more fatiguing than the barehand. The recovery rates (trials 8-14) revealed the same differences. Neither of the glove conditions achieved full recovery while in the barehand condition, full recovery was achieved by Trial 12 (see Fig. 5-19).

The pressurized glove average rating on Trial 7 was 4.42 which corresponds to just below a complete fatigue rating. Hence the subjects subjective estimate of fatigue was that they were nearing exhaustion.

Post Hoc Fatigue Ratings

The average post hoc fatigue ratings are shown in Table 5-26 and graphically presented in Fig. 5-20. A strong effect of glove condition was observed. For the barehand fatigue trials the average fatigue rating was 1.9. In the unpressurized glove condition the rating was increased by 63% to 3.1. In the pressurized glove

Table 5-25 Average Real-time Fatigue Rating

Trial	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
1	1.10 (0.32)	1.20 (0.42)	1.10 (0.32)
2	1.35 (0.47)	1.90 (0.74)	1.90 (0.74)
3	2.05 (0.83)	2.75 (1.03)	2.90 (0.88)
4	2.50 (1.18)	2.98 (1.00)	3.56 (1.01)
5	2.80 (1.40)	3.35 (1.11)	3.90 (0.99)
6	2.80 (1.40)	3.58 (1.14)	4.39 (0.70)
7	3.08 (1.49)	3.80 (1.14)	4.42 (0.71)
8	2.40 (1.26)	2.95 (0.76)	3.85 (1.06)
9	2.25 (1.09)	2.55 (0.96)	3.40 (1.26)
10	1.60 (0.84)	2.25 (1.14)	3.10 (1.37)
11	1.35 (0.47)	1.80 (0.79)	2.70 (1.25)
12	1.10 (0.32)	1.65 (0.82)	2.30 (1.25)
13	1.10 (0.32)	1.40 (0.52)	2.10 (1.29)
14	1.10 (0.32)	1.50 (0.71)	2.00 (1.33)

Table values are expressed in means; standard deviations are in parentheses.
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Table 5-26 Average Post Hoc Fatigue Ratings

Glove Condition		
Barehand	Glove-0 psid	Glove-4.3 psid
1.90 (1.60)	3.10 (0.99)	4.90 (2.77)

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condition the rating was increased 157% above barehand to 4.9. Hence the subjects perceived that their fatigue was more influenced by the pressurization of the glove than the glove itself.

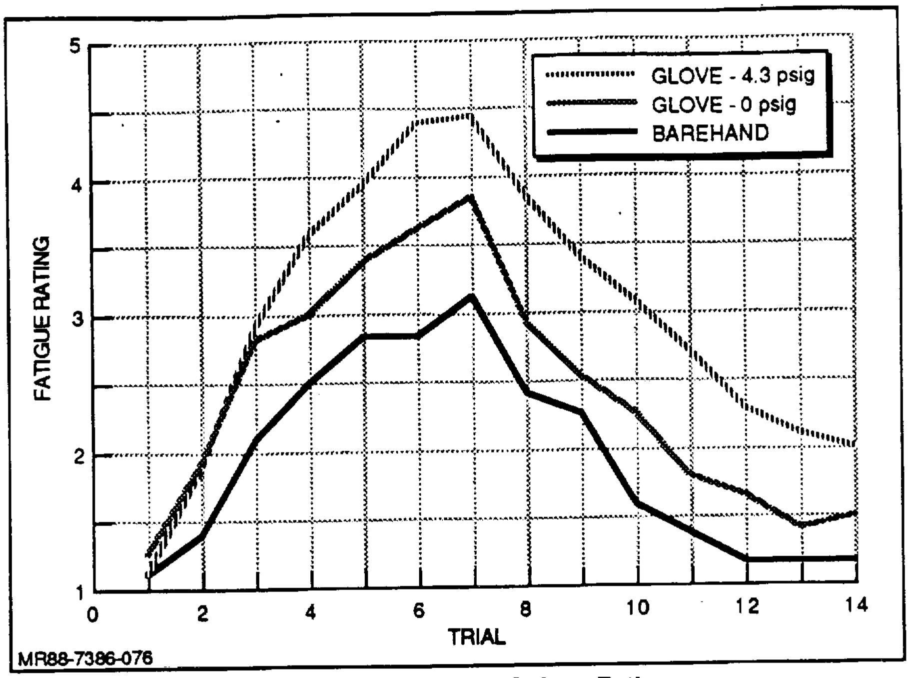

Fig. 5-19 Average Real Time Fatigue Rating

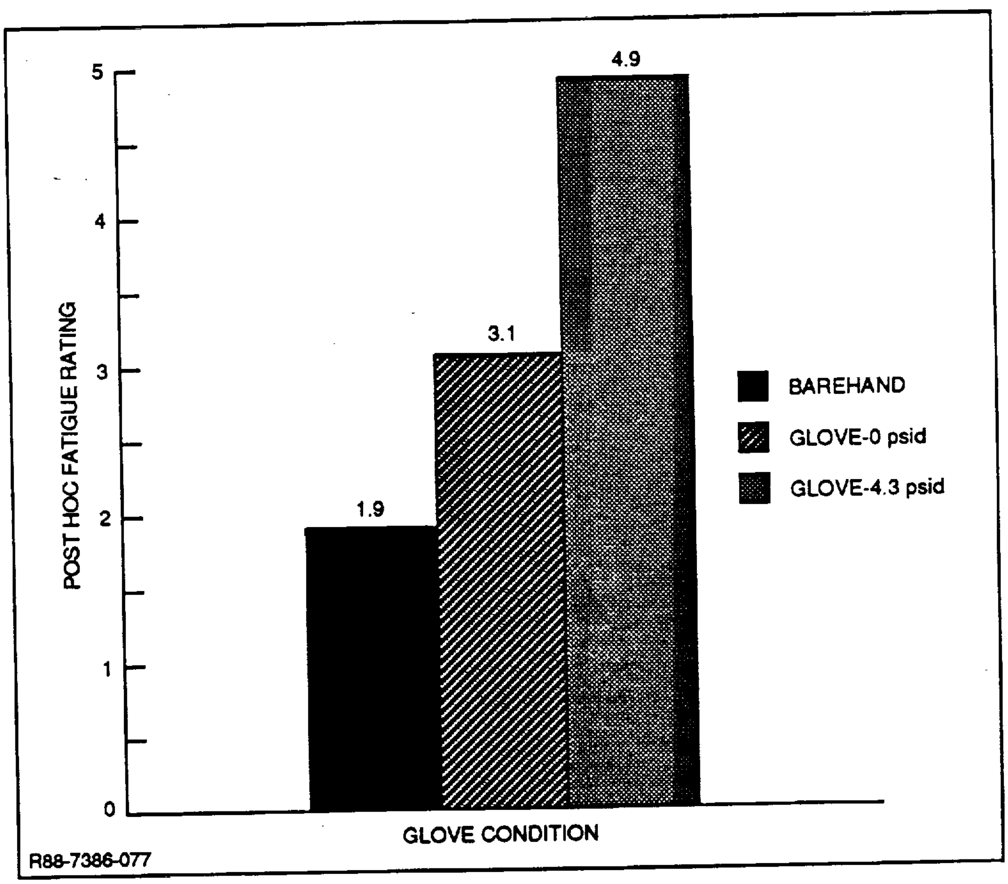

Fig. 5-20 Average Post Hoc Fatigue Rating

5.6.3 Performance Decay

Data on performance decay was obtained by measuring the amount of work produced using the BTE during the isotonic muscle contractions. These data are presented in Table 5-27 as a function of glove condition and trial. A comparison of Trial 1 work values indicates that the amount of dynamic work the subject was able to produce was greatly affected by glove condition. Subjects in the unpressurized glove condition were only able to produce 54% of the work produced barehanded and in the pressurized glove condition only 41%. Over all six trials, work with the unpressurized glove was 61% of barehand and with the pressurized glove was only 32% of barehand.

Performance decay resulting from fatigue effects are represented by negatively sloping work curves over trials. However, due to the large differences in total work performed, it was appropriate to normalize the data to a standard reference value. (The reason for this data transformation becomes apparent if one considers that a 10 in-lb drop in work varies in meaning if the initial work value is 200 in-lb as compared with an initial value of 50 in-lb). The data for trials 2 through 6 were transformed to percents of work produced in the initial trial (Trial 1) where fatigue is presumed to be minimal relative to later trials.

Table 5-27 Average Fatigue Work Output, in.-lb

Trial	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
1	214.92 (82.45)	116.23 (61.03)	88.86 (74.99)
2	230.84 (169.91)	141.73 (93.74)	84.37 (73.89)
3	230.98 (120.49)	128.35 (128.28)	62.58 (55.69)
4	189.53 (61.74)	131.24 (113.49)	60.64 (56.56)
5	203.29 (85.52)	126.20 (112.71)	58.67 (66.38)
6	193.96 (79.18)	141.69 (128.53)	54.83 (50.18)

Table values are expressed in means; standard deviations are in parentheses.

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The performance decay fatigue curve data as a function of glove condition and trial is presented in Fig. 5-21. Derivation of fatigue curves were based on a linear regression fit. Fatigue is reflected by a negative sloped line, reflecting a drop in performance over trials. It is apparent from these data that there was a strong effect of glove pressure. This is indicated by the strong negative slope in the pressurized glove condition. Subjects lost approximately 8% performance on each trial as indicated by the slope of -8. By contrast, the slopes for the barehand and unpressurized glove conditions were -3 and +2, respectively. It is not clear why no performance decay (that is, performance loss over trials relative to Trial 1 performance) was observed in the unpressurized glove condition. This may have been due to an abnormally low work output in Trial 1 relative to the other trials. Even considering this factor there was clearly no drop in performance over trials while there was in the other two conditions. However, the drop in performance with the pressurized glove is convincing and dramatic with the major decay occurring between trials 2 and 3 suggesting that fatigue was rapid.

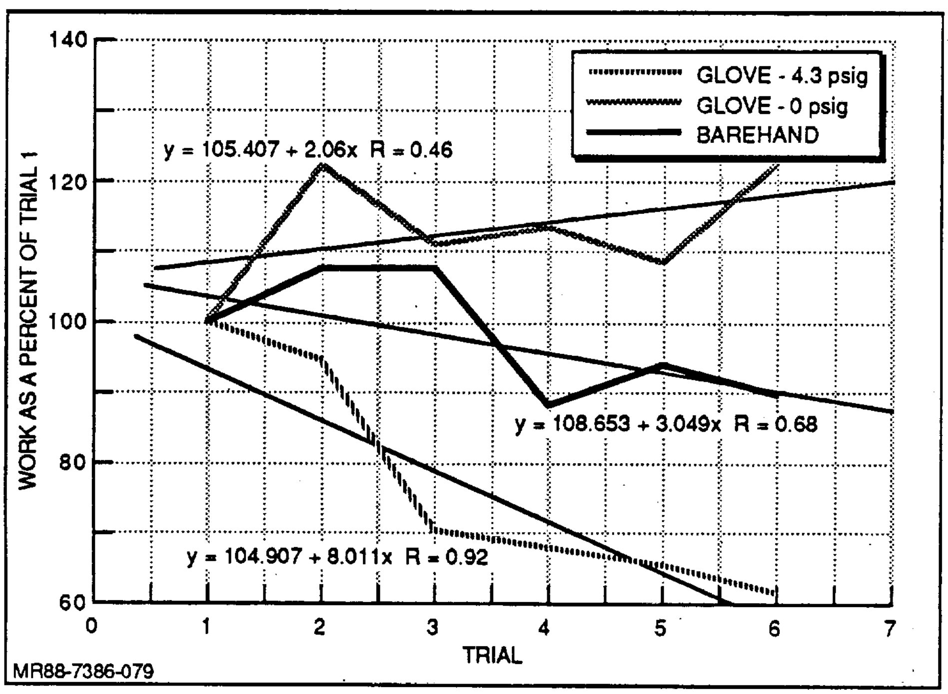

Fig. 5-21 Average Work Performance Decline

5.7 COMFORT RATINGS

Comfort ratings were obtained after each fatigue test. Two comfort rating scales were used. The first obtained the subject's assessment of the effect of comfort/discomfort on task performance (see Fig. 4-17). This scale used task performance as an objective reference with which to obtain general comfort ratings. The second was a rating of specific glove-hand interaction and hand environment problems (see Fig. 4-19). This second rating form also provided for subjects to indicate where on their hands problems were encountered and to elaborate on the nature of their difficulty. Some of the questions were not applicable to the barehand condition.

Table 5-28 contains subjects ratings on the items from both scales as a function of glove condition. Note that the first item was scored on a nine-point scale while the others were scored on a three point scale.

Table 5-28 Average Comfort Ratings Following as a Function of Glove Condition & Comfort Parameter

Rating	Glove Condition		
	Barehand	Glove-0 psid	Glove-4.3 psid
Discomfort *	0.70 (1.89)	2.20 (2.90)	4.60 (3.37)
Fatigue	1.90 (1.66)	3.10 (0.99)	4.90 (2.77)
Chafing	N/A	0.10 (0.32)	0.33 (0.50)
Cutting	N/A	0.00 (0.00)	0.00 (0.00)
Pinching	N/A	0.40 (0.52)	0.40 (0.70)
Numbing	N/A	0.20 (0.42)	0.22 (0.44)
Hot	N/A	0.40 (0.52)	0.67 (0.71)
Cold	N/A	0.00 (0.00)	0.00 (0.00)
Wet Feeling	N/A	0.40 (0.70)	0.67 (0.71)
Dry Feeling	N/A	0.00 (0.00)	0.00 (0.00)

Table values are expressed in means; standard deviations are in parentheses.
* Discomfort ratings were on a nine-point scale. All others were on a three-point scale.
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A large effect of glove condition was found on the general comfort/discomfort rating. This effect can be clearly seen in Fig. 5-22. Both a glove effect and a pressure effect were evident. The pressurized glove was rated approximately twice as uncomfortable as the unpressurized glove (and almost six times more uncomfortable than the barehand).

Questions regarding the nature of the discomfort were a part of the second rating scale and these data are presented in Table 5-28. There was not a great deal of difference between the unpressurized and pressurized glove. Subjects indicated problems with chafing, pinching, numbing, heat, and wet feeling. Of these the pressurized glove was rated higher in chafing, heat, and wet feeling.

Generally these ratings were low: falling between 0 (no problem) and 1 (moderate problem). However, it should be noted that the ratings were obtained

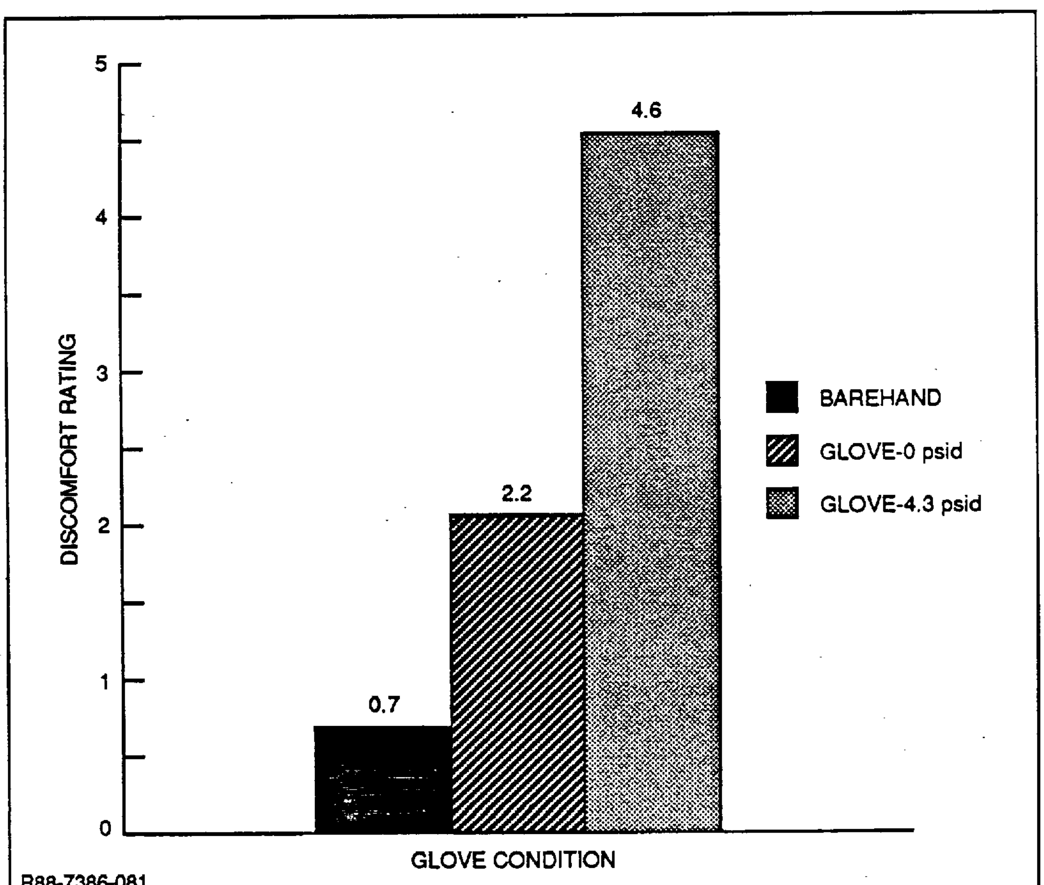

Fig. 5-22 Average Discomfort Ratings as a Function of Glove Condition

following fatigue tests where subjects only wore the gloves for approximately 10 minutes and only half of that involved working the gloves (The latter half was the recovery phase). Every effort was made during this study to design a protocol that would not adversely affect the subject's hands. The comfort data must be interpreted in light of these factors.

Subjects were also asked to indicate the nature of their discomfort and to identify where on the hand the problem was experienced. In the unpressurized glove conditions, four subjects (S) identified areas of discomfort:

- S No.3 - chafing between thumb and index finger of right hand
  - numbing between the middle and index finger of right hand
- S No.6 - heat build-up on the right hand thumb
- S No.9 - pinching on the right hand pinky
  - numbing on the palm side of the right hand
- S No.10- pinching in the thumb crotch area of the right hand.

In the pressurized glove condition, 7 of the 10 subjects identified areas of discomfort.

- S No.1 - pressure in the middle three fingers of the left hand S No.2- chafing of the pinky of the left hand
- S No.3 - numbing of the area between index finger and thumb of right hand
  - chafing in the same area
  - numbing of the areas below the pinky and between the thumb and index finger of the left hand
  - chafing of the same area
- S No.4 - chafing of the area below the pinky nail of the right hand
  - pinching of the thumb tip of the right hand
- S No.6 - pinching of the thumb of the right hand
  - heat build-up in the right hand thumb crotch
- S No.9 - pinching of the palm side and pinky crotch of the right hand
- S No.10 - pinching of the right hand thumb crotch.

Based upon these comments it appears that the glove-hand interaction problems became worse when the glove is pressurized.

6 - SUMMARY & CONCLUSIONS

6.1 SUMMARY OF TEST RESULTS

The tests developed for this study and the data collected were directed toward meeting several study objectives specified in Section 3 - Objectives. Briefly these were to:

1. Develop a set of test methods designed to assess basic hand capabilities and which are sensitive within a range from a bare hand to a hand in a pressurized EVA glove.
2. Develop a database of barehand and gloved hand capability for a representative EVA glove (the ILC 1000 Series glove).
3. To evaluate a series of test specific objectives relating to range of motion, strength, tactile perception, dexterity, fatigue, and comfort.

In evaluating these objectives with respect to the data analyses presented in the previous section, we will first summarize the results with respect to the latter two objectives (which are specifically data related). We will then assess the test methods developed in terms of the initial objectives.

The second objective was directed towards examining the effects of: (1) an EVA glove alone (no pressure differential), (2) a glove with pressure (4.3 psid), and (3) hand size, on the six basic hand capabilities assessed. The results of these effects are summarized in Table 6-1. The table is organized so that an overview of the results for each specific dependent variable within each test is summarized. The columns for "glove" and "glove with pressure" express the data as a function of performance. This standardization of the data allows comparisons across dependent variables and across the tests within each hand capability domain so that the general conclusions can be derived. The last column on the table addresses the third objective by summarizing the effects of test specific objectives. The results for individual test variables are also presented, where appropriate, in the other table columns. The results for each hand capability area are summarized below.

Table 6-1 Summary of the Test Results (Sheet 1 of 5)

CAPABILITY DOMAIN	TEST	MEASUREMENT (DV)	TEST PARAMETER EFFECTS SUMMARY*: HAND SIZE	GLOVE ALONE	GLOVE + PRESSURE	TEST SPECIFIC EFFECTS
RANGE OF MOTION	Photometrics	• Degrees	• Significant Negative Correlation With: - MCP1 Extension - MCP1 Flexion - MCP2 Flexion • Positive Correlation With Wrist Pronation • All Others Were Not Significant • Significant Correlations Reported Were Not For All Glove Conditions	• MCP Group Flexion-78% • MCP Group Extension-85% • PIP1 Flexion-29% • PIP1 Extension-69% • MCP2 Flexion-80% • Wrist Extension-86% • Wrist Pronation-77% • Wrist Suppination-93% • No Effect On: - PIP1 Extension - MCP1 Flexion - MCP1 Extension - Wrist Flexion - Wrist Adduction - Wrist Abduction	• MCP Group Flexion-69% • MCP Group Extension-18% • MCP2 Flexion-68% • Wrist Extension-55% • Wrist Pronation-63% • Wrist Suppination-75% • Wrist Abduction-81% • No Effect On: - PIP1 Flexion - PIP Extension - PIP1 Extension - MCP1 Flexion - MCP1 Extension - Wrist Flexion - Wrist Adduction	

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* The effects of glove alone and glove + pressure are expressed as percentages of barehand performance on each task variable.

Table 6-1 Summary of the Test Results (Sheet 2 of 5)

			TEST PARAMETER EFFECTS SUMMARY*			
CAPABILITY DOMAIN	TEST	MEASUREMENT (DV)	HAND SIZE	GLOVE ALONE	GLOVE + PRESSURE	TEST SPECIFIC EFFECTS
STRENGTH	BTE	• In-lbs • Lbs	• High Positive Relationship With Cylinder Grip • High Positive Relationship For Force Measures • Low Relationship For Torques	• Cylinder Grip 65% • Little Effect On Other Measures	• Cylinder Grip 53% • Little Effect On Others	• NA

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* The effects of glove alone and glove + pressure are expressed as percentages of barehand performance on each task variable.

Table 6-1 Summary of the Test Results (Sheet 3 of 5)

CAPABILITY DOMAIN	TEST	MEASUREMENT (DV)	TEST PARAMETER EFFECTS SUMMARY			
			HAND SIZE	GLOVE ALONE	GLOVE + PRESSURE	TEST SPECIFIC EFFECTS
TACTILE PERCEPTION	Two-point Discrimination	• Error Frequency	• no relationship	• 300%	• 430%	NA
		• Gap At Which Subject Perceives Two Points	• Stronger Correlation With Glove Condition	• 250%	• 300%	NA
	Object Identification	• Percent Of Correct Shape & Size Identification	• No relationship	• shape 78% • size 92%	• shape 83% • size 92%	• Overall No Shape Effect • Large Size Effect-Worse Performance With Larger Size
		• Response Time	• No Relationship	• 260%	• 291%	
	Grip Force Control Perception Test	• Safety Margin (Holding Grip Force-slip Force)	• Strong Relationship In Barehand Condition • Finger Grip Large For Larger Subjects • Not Much Relationship For Palm Grip	• 186%	• 211%	• Grip Type Important 52% Greater With Palm Grip • Weight And Handle Type Not As Important

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Table 6-1 Summary of the Test Results (Sheet 4 of 5)

CAPABILITY DOMAIN	TEST	MEASUREMENT (DV)	TEST PARAMETER EFFECTS SUMMARY: HAND SIZE	GLOVE ALONE	GLOVE + PRESSURE	TEST SPECIFIC EFFECTS
DEXTERITY	Pegboard	• Number of Pegs Inserted	• Significant for handling small pegs with pressure glove only	• 56%	• 21%	• No Peg Size Effect
		• Number of Pegs Dropped	• NA	• No Difference	• 200%	• Very Few Pegs Dropped
	Nut and Bolt Assembly	• Number of Assemblies Made	• Slight Trend Toward More Assemblies By Larger Hand Sizes	• 38%	• 15%	• Fewer Assemblies Made With Smaller N & B
		• Number Dropped	• No Relationship	• 227%	• 260%	• Fewer Drops As Size Increased
	Knot Tying Test	• Seconds To Complete	• Negative Corr. In Pressure Glove Condition • Less Relationship In Other Conditions	• 195%	• 400%	• Thin Rope Took Slightly Longer To Tie

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Table 6-1 Summary of the Test Results (Sheet 5 of 5)

CAPABILITY DOMAIN	TEST	MEASUREMENT (DV)	TEST PARAMETER EFFECTS SUMMARY: HAND SIZE	GLOVE ALONE	GLOVE + PRESSURE	TEST SPECIFIC EFFECTS
FATIGUE	Physiological Muscle Fatigue	• Change In EMG Median Frequency Over Trials	NA	• Finger Flexors 457% • Wrist Ext 73% • Thumb Flex 124%	•829% •54% •195%	• Fatigue Effect Depended On Muscle
	Subjective	• Rating Scale During Fatigue Protocol	NA	• 123%	• 144%	NA
		• Ratings After Protocol	NA	• 163%	• 257%	NA
	Performance Decline	• Trial 1 Work	NA	• 54%	• 41%	NA
		• Average Work Overtrials	NA	• 61%	• 32%	NA
		• Slope Of Decay Curve	NA	• Not Much Different From Barehand	• Much Greater Fatigue Than Barehand	NA
COMFORT	Questionnaire	• Nine-Point General Discomfort Scale	NA	• 200%	• 600%	NA
		• Three-Point Rating Scales Identifying Specific Problems	NA	NA	NA	• Not Much Difference Between Pressurized & Unpressurized Glove • Problems Indicated w/ Chafing, Pinching, Numbing, Heat, & Wetness

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Range Of Motion

Several conclusions regarding the effect of the glove and pressure on ROM can be made. It should be noted, however, that some limitations to the video technique were observed. Thus, the quantitative analysis for the ROM experimental data is not as accurate as the qualitative trends observed. When measuring the range of motion using the stop action video, it was often difficult to locate the centers of rotation of the joints of interest, particularly for the gloved hand. This introduces a continuous variable in the measurement process. All trends observed should be considered as general trends, rather than judging quantitative decreases in the range of motion.

To summarize the main effects observed on range of motion:

- No effect - MCP1 flexion, MCP1 extension, wrist flexion, wrist adduction
- Glove effect only - MCP group flexion, PIP1 flexion, PIP1 extension
- Pressure effect only - wrist abduction
- Glove and pressure effects - MCP group extension, MCP2 flexion, wrist extension, wrist pronation, wrist suppination.

A more detailed breakdown of the results from the ROM tests are presented in Table 6-1. The outcome of these tests suggest that the EVA glove used in these tests had a fairly good thumb design. Little effect on MCP1 flexion or extension was observed.

In general the pressure effects were different for flexion and extension. The reason pressure has effect on MCP extension but not flexion is that the finger extensor muscles are much weaker than the flexor muscles, thus you see an incremental effect with pressure. Some astronauts train hand strength by gripping a rubber ball, etc, but this suggests that the extensors should be exercised.

Strength

Conclusions on strength effects can be drawn from two of the tests performed. The strength test evaluated brief, static, maximum strength performance and the fatigue test Trial 1 data show dynamic work performance for a one minute gripping task (where prolonged fatigue effects should not have occurred yet). On strength measures it was clear that the effects were related to the type of motion produced. With whole hand motions such as the cylinder grip, a glove alone reduced strength to 65% of barehand and the pressure further reduced strength to 53% of barehand. Trial 1 of the fatigue test also employed a cylinder grip but in a negative gripping task. Here the glove alone reduced work to 54% of barehand and the pressure further reduced strength to 41% of barehand. One can conclude from these data that whole hand strength/work capacity is specifically reduced by putting on the EVA glove. It is further reduced by pressurizing the glove. Relative to the construction of the glove itself (which of course is designed for pressure containment as well as other factors), the incremental effect of pressure on strength/work is smaller.

Looking at pinch type hand motions, a different result is obtained. Neither the glove or the additional pressure had much impact on strength. This finding is consistent with other glove research indicating that the glove can improve some finger strength measures especially those involving torque production. The benefits derived from hand protection and increased coefficient of friction associated with wearing a glove apparently compensates for loss of strength. Also our tests involved very small glove deflections and no repetitious motions, and these test features tended to minimize glove effects.

With respect to hand size, only the cylinder grip measure had a strong positive relationship with hand size.

Tactile Perception

Perhaps the most obvious conclusions to be derived from the results of tactile perception testing (summarized in Table 6-1) are that:

- The EVA glove causes a very large degradation in tactile perception
- The addition of pressure differential from 0 to 4.3 psid degrades performance only slightly beyond that of the glove itself.

The most common measure of tactile perception is two point discrimination. This is due to two factors. First, the measure is directly tied to the density of tactile nerves and to the factors which affect the functioning of these nerves. Hence the measure has a very direct tie to the physiological basis for tactile perception. Second, two-point discrimination is very highly correlated with many other aspects of tactile perception such as pressure detection, vibration detection, etc(26). The glove increased the gap at which two points were detected to 250% of barehand performance. Similar results were obtained for error frequency and response time on the object identification test. The validity of the two-point discrimination test apparatus is supported by the close agreement between the results obtained for the two-point gap width detection threshold in our sample (x = 0.08 in.) and that reported in the literature using classical aestheometer methodology-(0.09 in.)(25).

The control force perception test yielded similar results which is interesting. The glove reduced tactile perception causing subjects to increase their applied grip force safety margin to 186%. This is interesting because grip force is not itself directly related to perception, but is related to the safety margin with which one holds an object. Further, the magnitude of increased safety margin is similar to the percentage increase in two-point perception.

These results mean that the EVA astronaut is likely to hold objects with excessive force (greater safety margin than required) due to lack of tactile perception. Over time this will be associated with greater fatigue. The sensitivity of the test methodology is reflected in the differences between the two grip types in the control force perception test. Tactile sensitivity is greater in the fingers than in the palm of the hand. Thus one would predict safety margins to be less for the fingers if safety margin is actually based upon tactile feedback. The test data indicated that the safety margin of the palm grip was 52% higher than the finger grip.

No clear conclusions can be derived from the hand size correlations with tactile perception measures. In general, no relationship was found between the measures. There were suggestive trends in the two-point detection threshold in the glove conditions and in the barehand control force perception that tactile sensitivity was reduced in larger hands but these trends were not firm.

Dexterity

The results of the dexterity tests were quite consistent across the three tests and support the following conclusions:

- The unpressurized glove reduced dexterity performance by approximately 50% of barehand
- The incremental effect of the pressure differential was significant and reduced dexterity performance by approximately an additional 30%.

In the unpressurized glove condition dexterity was reduced by about 50% in the pegboard and nut and bolt assembly tasks while knot tying time was doubled. When using the pressurized glove, performance in the pegboard and nut and bolt test reduced to about 20% of barehand performance and knot tying time was increased to 400%.

These results support the independent contributions to dexterity loss from glove construction and pressure differential. This is different from the results in tactile perception performance which was predominantly influenced by the glove itself.

It was interesting that dexterity performance was not strongly affected by object size but some differences in the expected direction were observed, i.e.:

- Fewer assemblies completed for small nuts and bolts
- Fewer drops for larger sized assemblies
- Faster knot tying time for the larger diameter rope.

The effect was not as great as we expected considering the small size of the objects involved (which were quite a bit smaller than the objects typically handled by EVA gloved hands). This does not imply that EVA hardware can be designed smaller because other factors, such as fatigue, are involved. However it does show that small objects can be manipulated for short times if needed.

Hand size played a stronger role in gloved hand dexterity tasks than in tactile perception. The general trend was toward better performance with increased hand size in all three tests as represented by positive correlations in the peg insertion and nut and bolt assembly tasks and a negative correlation in the knot tying task.

Fatigue

The results of the fatigue evaluations were the most complex of all hand capability domains investigated. With respect to the physiological dimension of fatigue two conclusions emerge:

- The results of the EMG analysis indicate that fatigue effects are muscle specific and the pattern of fatigue across muscles is different in the gloved hand condition than the barehand condition

- In two of the three muscle groups evaluated, finger and thumb flexors, both glove and pressure effects were observed but their magnitudes were muscle specific (see Table 6-1). The wrist extensor muscles had a unique pattern of fatigue compared to finger and thumb flexors.

The quantitative EMG procedure was successful at measuring local muscle fatigue but a full understanding of the effects of the EVA glove and pressure will require a more thorough analysis of different hand tasks and how individual muscle groups are utilized. Future tests should place particular emphasis on determining how the muscles of the hand perform a task without the glove and how the muscle usage/fatigue profile changes once the glove is donned and pressure is added. The quantitative EMG procedure developed in this study will be ideally suited to this type of analysis.

It was found, for instance, that the pressurized glove condition was associated with a reduction of fatigue in the wrist extensor muscles. It is possible that the pressurized glove may have acted as an "air-splint" and thereby replaced the need for the wrist extensors to support the wrist while the hand was performing this particular task. This possibility is reinforced by the fact that much less support is provided by an unpressurized glove and, therefore, no appreciable reduction of fatigue from the barehand condition was seen at glove/0 psid condition. However, this difference in fatigue profile across muscles is very likely task-dependent, since, unlike our task, tasks involving wrist motion (e.g., pushing, pulling, or lifting) may result in excessive fatigue in the pressurized glove condition. This is because the increased stiffness provides an additional resistance for the muscles to overcome and the normal wrist and hand kinematics may be altered as well. Further studies are needed to explore these important considerations.

This type of effect was most evident in the finger flexors for both unpressurized and pressurized glove conditions. This hypothesis is supported by the fact that fatigue in the finger flexors for the glove/0 psid was doubled when the glove was pressurized (see Table 6-1). Stiffness, or resistance to movement, increases proportionately to pressure and, therefore, the finger flexors would have to sustain higher force levels when the pressure is increased from 0 psid to 4.3 psid. Physiologically this increase in muscle force output results in the recruitment of muscle fiber types that typically produce greater levels of lactic acid and other end-products(41,42) which are associated with fatigue. When a muscle has to sustain a contraction at a relatively high force level, ischemia (or reduced blood flow) may result(37,43) which tends to facilitate the accumulation of metabolites since their removal by blood flow is impeded.

The results of the subjective fatigue assessments were consistent across "real-time" and "post-hoc" measurements:

- Both glove and pressure provided independent and nearly equal components to fatigue ratings.

The performance decay data was very interesting. With respect to amount of work performed it can be concluded that:

- The unpressurized glove reduced the amount of work performed by approximately 40%
- The pressurized glove reduced the amount of work performed by an additional 30%.

Hence in terms of work performed, the glove and the pressure had unique contributions to work loss.

Fatigue, however, is reflected more in the decay in work over trials and, while this can be related to the amount of work performed, it is more appropriately assessed by the change in work performed from one trial to the next. Therefore, the change in work plotted across trials (work slope) provides a more accurated depiction of fatigue than the total work performed. Based upon this logic, the following conclusion can be drawn from a comparison of slope values:

- The glove itself had minimal impact on fatigue
- Pressure had a very significant and dramatic effect on fatigue.

The work performed over the fatigue trials in the pressure glove condition showed a rapid, monotonic decrease. The slope of the regression line plotted for these trials was -8 indicating an average loss of approximately 8% of work for each trial. It must be emphasized that these fatigue results are of course related to the specific task performed and glove used in this study. Fatigue is a very complex phenomenon and, more than any other capability area investigated, requires a comprehensive analysis of how different types of tasks, task demands, and hand action required interact to cause the fatigue process. For example, our task was a dynamic gripping task. We might expect results to be different if the task were a static holding task. The fatigue resulting from integrated, "real-world" types of tasks which are composed of a variety of hand demands is more complex. What we accomplished was to develop an approach that was based on a three dimensional analysis (physiological, subjective, and performance) to assess fatigue. This approach was successfully tested with one type of task, and should approach now be used to undertake a more thorough evaluation of the fatigue associated EVA gloves doing other tasks. Proof of the generality of specific magnitudes of the effects observed, as with results from any other hand capability domain, will require further testing using similar methods.

Comfort

An overall assessment of comfort was obtained using a nine-point scale that linked comfort to task performance. On this scale the following result was obtained:

- The unpressurized glove degraded comfort by 100% from barehand comfort
- The pressurized glove degraded comfort by 600% from barehand comfort.

Thus it appeared that like degradation in work performance, glove pressure had a more significant effect on comfort than did the glove itself.

7 - RECOMMENDATIONS

Several recommendations regarding concerns with and changes to the test protocol can be offered on the basis of this program.

Range of Motion Measurement

- Videotape provided an excellent means of recording the dynamic characteristics of hand range of motion. One limitation, however, as noted earlier is that when recording the gloved hand the method may suffer from a lack of high precision. This is due to the difficulty of knowing precisely where the fingers are located. New (and expensive) methods are available, e.g., optical flex technology, which may overcome this problem, however, their use in an EVA glove program must be established
- When using the photometric technique, great care must be taken to assure that the camera is aligned perpendicular to the plane of motion being assessed. We encountered some difficulties keeping subject's hands in the proper orientation during filming. A hand support fixture or guide would help minimize this source of error
- Design of the glove box utilized in the study did not permit the taking of actual measurements "in the box." This needs to be accomplished for two reasons. One, to collect data on certain thumb motions which cannot easily be measured from videotape. Second, to permit a comparison of videotape vs more traditional methods of measurement.

Strength Measurement

- The instrument used in these tests was a BTE work simulator. Its advantage was that many different tools could be utilized, thus providing a means to measure a wide variety of strength parameters. Several concerns were noted, however, pertaining to the reliability of the instrument as a research tool. First, the device could not be calibrated at the test site and had to be sent to the manufacturer for calibration. Second, when set to one specific level of resistance, the actual resistance achieved was not uniform. We would recommend the use of more precise dynamometers for strength measurement.

Two Point Discrimination Measurement

- This instrument and the proposed method worked very well. One problem encountered was difficulty specifying exactly what location on the fingertip is being used when the subject has the glove on. Like the problem with range of motion measurement, the precise location of the fingers and hand within the glove is not known.

Object Identification Measurement

- While the method utilized to present small objects to the "blind" subject was very successful, this test did not discriminate well between the test conditions. Despite using very small objects, subjects were still able to discriminate between shapes.

Grip Force Perception Measurement

- The results of this test were similar to those of the two-point discrimination test so retaining both in the protocol is not warranted by the data. However, several aspects of this test support its use in further investigation. First, it has a much clearer relationship to EVA tasks than the two-point discrimination test, therefore, its results are more readily understood. Second, the test clearly ties tactical perception with the factors that contribute to hand fatigue. Since this is a major EVA issue, further investigation with this test may lead to a better understanding of the fatigue process. Third, this test was rather unique so its value above the other test may not have been demonstrated in this test program.

Dexterity Tests

- There was a high degree of similarity in dexterity test results. Of the tests performed, the nut and bolt assembly and the knot tying were the most successful in terms of simplicity of equipment and test procedures
- The pegboard test proved more difficult than expected. The test was initially conceived as a one-handed dexterity test emphasizing accurate positioning and alignment. Subjects could not manipulate the pegs easily with one hand so the procedure was modified to a two hand operation, which in

terms of hand dexterity requirements was essentially the same as the simpler nut and bolt test

- The knot-tying test worked well but was subject to more style variations associated with individual differences
- Since test results were similar across tests, a single dexterity test can be selected. The nut and bolt assembly test was the simplest to set-up and perform, could be held more consistent in procedure than the other tests, and yields precise data. Hence, we would recommend its selection for further glove testing.

<u>Fatigue Tests</u>

- The fatigue tests clearly need more research. The data produced in this test were important and interesting, but a more comprehensive analysis of test equipment and procedures is needed
- The quantitative EMG tests were very successful. Before a standardized procedure can be established more work needs to be performed in the areas of electrode design for use with pressure gloves, sensitivity to electrode siting, identification of appropriate hand and forearm muscle groups for glove evaluation, and in data presentation (such as developing a "time constant" approach to fatigue date representation). The procedures and analysis methods used in this study laid significant groundwork for the further investigation of this method
- Problems were encountered in utilizing the BTE work simulator. These problems were essentially the same as identified in the strength section. This gave us some concern about the consistency of a subjects data from trial to trial. This problem should not have been a major problem for data averaged across subjects, but it probably did increase the error variance (noise) in the results.

<u>Comfort Measurement</u>

- The rating scales developed in this study worked well, however, they were rather general. More discriminating scales should be developed to better isolate the factors which contribute to discomfort
- Objective measures of comfort need to be investigated.

Glove Box

- The glove box used in these tests was not designed to accommodate such a wide range of hand evaluations. Thus, the design of the test equipment and procedures was greatly constrained. The three major problems with the box were:
  - In ability to adjust shoulder port separation distance
  - When pressurized the gloves extended nearly to the opposite side of the glove box leaving very little room for test equipment
  - No provisions for a second set of hands, either a test conductor or second subject.

Further analysis of the impact of EVA gloves on hand capabilities such as dexterity and fatigue would greatly benefit from a glove box designed for this type of testing.

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APPENDIX A
LITERATURE REVIEW TABLES

Table A-1 Literature Review (Sheet 1 of 7)

AUTHOR	YEAR	GLOVE TYPE	METHOD	IND VARIABLES	DEP VARIABLES	TESTS	SAM SIZE	STATS	RESULTS
Johnson, R. & Sleeper, L.	1986	Hazardous materials	Lab	Barehand/gloves Protective hardware	Dexterity	• Purdue Pegboard • O'Connor finger dexterity	22	Descriptive ANOVA	• Gloves lowered dexterity by approximately 42% on O'Connor and 60% on Purdue • Learning effects were observed across several days • Mask had no effect
King, J and Frelin, A	1982	Hazardous materials	Lab	Barehand Gloves	Dexterity	Medical task simulations	9	Descriptive ANOVA	• Gloves lowered dexterity by 23 to 36% • Learning effects were observed
Michels, J. & Rush, W.	1982a 1982b	Hazardous materials	Field	Barehand Gloves	Dexterity Comfort Per-Tact	• Communications; maintenance and installation simulations • Rating Scales	?	Descriptive T-Test ANOVA	• All gloves reduced performance from barehand • Gloves differed in dexterity and tactility as determined by task times and subjective ratings • Learning effects were observed
Bensel, C	1980	Hazardous materials	Lab	Barehand Gloves Sex	Strength Dexterity	• Torque Test • Minnesota Rate of Mol. • O'Connor Finger Dexterity • Bennet • Cord Manipulation and Cylinder Stringing Test • Rifle disassembly/Assy	12	Descriptive ANOVA	• Sex effects on torque test only. Male 30% higher • Glove torques ranged from 75 to 175 of barehand • Glove Increases on time ranged from: - Minnesota 110-175% - O'Connor 118-188% - Cord manip. 160-260% - Bennet 113-137% - Rifle 114-186% • Learning effects leveled between 4-8 sessions
Cochran, D; et al	1986	Assorted	Lab	Barehand Gloves	Strength	Dynometer	7	Descriptive ANOVA	• Gloves degraded strength from 7.3 to 16.8% • More force was used to do a task when gloves were worn (noted)
Taylor, R & Berman, T.	1982	Flying	Lab	Barehand Gloves	Dexterity Per-Tact Positioning	Washer test Minnesota O'Connor Positioning Task Purdue Assembly "Two rulers" tactity test	12	Descriptive ANOVA	• Full glove assembly affected performance relative to barehand - Washer Test 132% longer - Minnesota 120% longer - O'Connor 145% longer - Positioning 111% longer - Purdue 37% of performance - Tactilityn 189% larger • Positioning and dexterity tests were lowly correlated • Tactility had a dominant effect on dexterity tasks • Mobility had a dominant effect on positioning tests

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APPENDIX B
TEST DATA FORMS

LIST OF FORMS

- Participant Consent Form
- Background Questionnaire
- Range of Motion Data Record
- Hand Strength Data Record
- Two-Point Discrimination Data Record
- Grip Force Control Data Record
- Object Identification Data Record
- Pegboard Test Data Record
- Nut and Bolt Assembly Data Record
- Knot Tying Data Record
- Fatique Protocol - Test Conductors Form
- Fatigue Protocol - Assistants Form
- Subjective Evaluation Forms
  - Fatigue
  - Comfort/Discomfort
  - Test Subjects Comments and Evaluation

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EVA LIMITATIONS STUDY
PARTICIPANT CONSENT FORM

NAME: ______________________ (Please print)

INSTRUCTIONS

The purpose of this form is to inform you of your rights as a voluntary participant in the study. Please read the study description below and sign your name at the bottom if you agree to take part in the study.

The objective of this study is to develop tests which measure the effects of wearing an EVA glove on a person's ability to perform simple tasks. As a participant in the study you will be asked to perform a series of tasks including finger and hand motions, finger and hand strength tasks, object identification, nut and bolt assembly, and similar tasks. You will be asked to perform these tasks with your bare hands and while wearing EVA gloves. Data will be collected during these tests trials. These data will be used to evaluate how successful the tasks are for EVA glove testing. The data will not be used to assess an individual participant's performance. All data will be tabulated across the entire set of participants. The test will require about two days and will pose no physical threat. You will have the right to discontinue your involvement at any time.

CONSENT

I have read the study description and agree to voluntarily participate in the EVA Limitations Study.

______________________ ______________
Participant's Signature Date

______________________ ______________
Test Conductor's Signature Date

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EVA LIMITATIONS STUDY
BACKGROUND QUESTIONNAIRE

NAME: ______________________ (Please print)
DATE: ______________________

1. Have you had any medical problems with your hands or arms that have required a doctor's attention?

   YES NO (Circle one) If YES, please describe. ______________________

2. Do you have any other problems associated with your hands or arms? YES NO (Circle one)

   If YES, please explain. ______________________

3. Have you had any illness within the last week or two? YES NO (Circle one)

   If YES, what was the nature of the illness? ______________________

4. Have you taken any medication within the last two weeks? YES NO (Circle one)

   If YES, give name of medication. ______________________

   Are you still taking medication? YES NO (Circle one)

   If NO, when did you stop taking it? ______________________

5. Do you engage in any work or leisure time activities that regularly exercise your hands or arms?

   YES NO (Circle one)

   If YES, how often do you engage in these activities? ______________________

   What is the average duration of each occurrence? ______________________

6. What is your occupation? ______________________

   Does your job require strenuous use of your hands and/or arms? YES NO (Circle one)

7. Have you ever used EVA gloves? YES NO (Circle one)

   If YES, in what context? ______________________

   When was that? ______________________

   What type of EVA gloves were they? ______________________

EVA LIMITATIONS STUDY
RANGE OF MOTION DATA RECORD

NAME:
TEST CONDITION: Bare G-0 G-2.3 G-4.3
TEST CONDUCTOR:
COMMENTS:

SUBJECT CODE: 133
TEST COND. CODE:
DATE:

PARAMETER	VALUE	SOURCE
Thumb Opposition	cm	Direct Measurement
MCP Group Flexion	degrees	Videotape
MCP Group Extension	degrees	Videotape
MCP 1 Flexion	degrees	Videotape
MCP 1 Extension	degrees	Videotape
MCP 2 Flexion	degrees	Videotape
PIP 1 Flexion	degrees	Videotape
PIP 1 Extension	degrees	Videotape
PIP 2 Flexion	degrees	Videotape
Wrist Adduction	degrees	Videotape
Wrist Abduction	degrees	Videotape
Wrist Pronation	degrees	D-Handle Measurements
Wrist Suppination	degrees	D-Handle Measurements
Wrist Flexion	degrees	Videotape
Wrist Extension	degrees	Videotape

II

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EVA LIMITATIONS STUDY
HAND STRENGTH DATA RECORD

NAME: ______________________ SUBJECT CODE: 133

TEST CONDITION: Bare G-0 G-2.3 G-4.3 TEST COND. CODE: ______

TEST CONDUCTOR: ______________________ DATE: ______

COMMENTS:

CDAB

TRIAL	PARAMETER	TOOL	MEAS. 1 VALUE	MEAS. 2 VALUE
1	Cylinder Grip Pronation	601	in-lbs	in-lbs
2	Cylinder Grip Suppination	601	in-lbs	in-lbs
3	Chuck Pinch Pronation	ILC MMU Knob	in-lbs	in-lbs
4	Chuck Pinch Suppination	ILC MMU Knob	in-lbs	in-lbs
5	Pulp Pinch Force	162	in-lbs	in-lbs
6	Key Pinch Force	162	in-lbs	in-lbs
7	Cylinder Grip Force	162	in-lbs	in-lbs
8	Key Pinch Pronation	202	in-lbs	in-lbs
9	Key Pinch Suppination	202	in-lbs	in-lbs

PARAMETERS:

- A = Pulp Pinch Force
- B = Key Pinch Force
- C = Cylinder Grip Force
- D = Key Pinch Pronation
- E = Key Pinch Suppination
- F = Chuck Pinch Pronation
- G = Chuck Pinch Suppination
- H = Cylinder Grip Pronation
- I = Cylinder Grip Suppination

TOOLS:

- J = BTE tool no.162 - Power grip & finger pinch pliers type handles
- K = 202 - Finger pinch
- L = 601 - Hand grip for supination/pronation
- M = ILC MMU Knob

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EVA LIMITATIONS STUDY
TWO-POINT DISCRIMINATION DATA RECORD

NAME: ______________________ SUBJECT CODE: 133

TEST CONDITION: Bare G-0 G-2.3 G-4.3 TEST COND. CODE: ______

TEST CONDUCTOR: ______________________ DATE: ______

COMMENTS:

B

TRIAL	RULER	RESPONSE/GAP WIDTH
1	No Gap	
2	Gap	
3	No Gap	
4	Gap	
5	No Gap	
6	Gap	
7	Gap	
8	Gap	
9	Gap	
10	Gap	

CODES

Ruler: 1 = Single Edge - No Gap
2 = Two Edge - With Gap

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EVA LIMITATIONS STUDY
GRIP FORCE CONTROL DATA RECORD

NAME:
TEST CONDITION: Bare G-0 G-2.3 G-4.3
TEST CONDUCTOR:
COMMENTS:

SUBJECT CODE: 133
TEST COND. CODE:
DATE:

4321

TRIAL	WEIGHT	HANDLE	GRIP	VERTICAL FORCE	HOLDING FORCE	SLIP FORCE
1	Heavy	Coarse	Fingertip			
2	Heavy	Coarse	Palm			
3	Light	Coarse	Fingertip			
4	Light	Coarse	Palm			
5	Heavy	Smooth	Fingertip			
6	Heavy	Smooth	Palm			
7	Light	Smooth	Fingertip			
8	Light	Smooth	Palm			

Weight = (L)ight or (H)eavy
Handle = (S)mooth of (C)ourse
Grip = (F)ingertip of (P)alm

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EVA LIMITATIONS STUDY
OBJECT IDENTIFICATION DATA RECORD

NAME: ____________________ SUBJECT CODE: 133

TEST CONDITION: Bare G-0 G-2.3 G-4.3 TEST COND. CODE: ________

TEST CONDUCTOR: ____________________ DATE: ________

COMMENTS:

Ⓑ

TRIAL	SHAPE*	SIZE*	RESPONSE	RESPONSE TIME
1	Cylinder	Small		sec
2	Sphere	Large		sec
3	Cylinder	Medium		sec
4	Rectangle	Small		sec
5	Cylinder	Large		sec
6	Rectangle	Medium		sec
7	Cube	Large		sec
8	Rectangle	Large		sec
9	Cube	Medium		sec
10	Sphere	Medium		sec
11	Sphere	Small		sec
12	Cube	Small		sec

*CODES

Shapes: 1 = Sphere, 2 = Cube, 3 = Cylinder, 4 = Rectangle

Sizes: 1 = Small, 2 = Medium, 3 = Large

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EVA LIMITATIONS STUDY
PEGBOARD TEST DATA RECORD

NAME:
TEST CONDITION: Bare G-0 G-2.3 G-4.3
TEST CONDUCTOR:
COMMENTS:

SUBJECT CODE: 133
TEST COND. CODE:
DATE:

TRIAL	PEG SIZE*	NUMBER INSERTIONS	NUMBER DROPPED
1	Medium	N per 30sec	N per 30sec
2	Medium	N per 30sec	N per 30sec
3	Large	N per 30sec	N per 30sec
4	Large	N per 30sec	N per 30sec
5	Small	N per 30sec	N per 30sec
6	Small	N per 30sec	N per 30sec

* CODES

Peg Size: 1 = Small
2 = Medium
3 = Large

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EVA LIMITATIONS STUDY
NUT & BOLT ASSEMBLY DATA RECORD

NAME: ____________________ SUBJECT CODE: 133

TEST CONDITION: Bare G-0 G-2.3 G-4.3 TEST COND. CODE: ________

TEST CONDUCTOR: ____________________ DATE: ____________

COMMENTS:

TRIAL	SIZE*	NUMBER ASSEMBLIES	NUMBER DROPPED
1	Medium	N per 30sec	N per 30sec
2	Medium	N per 30sec	N per 30sec
3	Large	N per 30sec	N per 30sec
4	Large	N per 30sec	N per 30sec
5	Small	N per 30sec	N per 30sec
6	Small	N per 30sec	N per 30sec

* **CODES**

Nut & Bolt Sizes: 1 = Small
2 = Medium
3 = Large

⑦

EVA LIMITATIONS STUDY
KNOT TYING DATA RECORD

NAME: ______

TEST CONDITION: Bare G-0 G-2.3 G-4.3

TEST CONDUCTOR: ______

COMMENTS:

SUBJECT CODE: 133

TEST COND. CODE: ______

DATE: ______

TRIAL	SIZE*	TIME TO COMPLETE
1	Thin	sec
2	Thin	sec
3	Wide	sec
4	Wide	sec

*CODES

Sizes: 1 = Thin Diameter Rope
2 = Wide Diameter Rope

EVA LIMITATIONS STUDY
FATIGUE TEST DATA RECORD
TEST CONDUCTOR'S FORM

NAME: ______________________ **SUBJECT CODE:** __________

TEST CONDITION: Bare G-0 G-2.3 G-4.3 **TEST COND. CODE:** __________

TEST CONDUCTOR: ______________________ **DATE:** __________

COMMENTS:

Tape No: __________

Initial Tape Footage Reading: __________

RECORDER CHANNELS (CHECK)		
CHANNEL	MUSCLE	CHECK
1	Finger Flexors	
2	Wrist Extensors	
3	Thumb Flexor	
4	FDI	
5	Synch Pulse	

MAXIMUM VOLUNTARY CONTRACTION (MVC) - BAREHAND				
TRIAL	PROCEDURE	CHECK WHEN COMPLETED	GAIN	COMMENT
1	100% MVC (5 sec.)			
•	Rest 1 min.	•	•	•
2	100% MVC (5 sec.)			
•	Rest 1 min.	•	•	•
3	100% MVC (5 sec.)			
•	(Optional)	•	•	•

MAXIMUM VOLUNTARY CONTRACTION (MVC) - IN TEST CONDITION				
TRIAL	PROCEDURE	CHECK WHEN COMPLETED	GAIN	COMMENT
1	100% MVC (5 sec.)			
•	Rest 1 min.	•	•	•

ohara06

FATIGUE/REST SEQUENCE				
TRIAL	PROCEDURE	CHECK	GAIN	COMMENTS
1	20% MVC (10 sec.)			
	1 min. Gripping Task			
2	20% MVC (10 sec.)			
	1 min. Gripping Task			
3	20% MVC (10 sec.)			
	1 min. Gripping Task			
4	20% MVC (10 sec.)			
	1 min. Gripping Task			
5	20% MVC (10 sec.)			
	1 min. Gripping Task			
6	20% MVC (10 sec.)			
	1 min. Gripping Task			
7	20% MVC (10 sec.)			
	30 sec. Rest			
8	20% MVC (5 sec.)			
	30 sec. Rest			
9	20% MVC (5 sec.)			
	30 sec. Rest			
10	20% MVC (5 sec.)			
	30 sec. Rest			
11	20% MVC (5 sec.)			
	2 min. Rest			
12	20% MVC (5 sec.)			
	2 min. Rest			
13	20% MVC (5 sec.)			
	2 min.Rest			
14	100% MVC (5 sec.)			

Final tape footage reading: ____________

ohara06

EVA LIMITATIONS STUDY
FATIGUE TEST DATA RECORD
ASSISTANT'S FORM

NAME: ____________________ **SUBJECT CODE:** ________

TEST CONDITION: Bare G-0 G-2.3 G-4.3 **TEST COND. CODE:** ________

TEST CONDUCTOR: ____________________ **DATE:** ________

COMMENTS:

MAXIMUM VOLUNTARY CONTRACTION (MVC) - BAREHAND			
TRIAL	PROCEDURE	FORCE	COMMENT
1	100% MVC (5 sec.)		
•	Rest 1 min.	•	•
2	100% MVC (5 sec.)		
•	Rest 1 min.	•	•
3	100% MVC (5 sec.)		
•	(Optional)	•	•

Calculate 20% Of Average MVC Force= ____________

Initial Ambient Room Temperature = ____________

MAXIMUM VOLUNTARY CONTRACTION (MVC) - IN TEST CONDITION			
TRIAL	PROCEDURE	FORCE	COMMENT
1	100% MVC (5 sec.)		
•	Rest 1 min.	•	•

ohara06

FATIGUE/REST SEQUENCE				
TRIAL	PROCEDURE	HAND TEMP	SUBJ RATING	FORCE*
1	20% MVC (10 sec.)			
	1 min. Gripping Task			
2	20% MVC (10 sec.)			
	1 min. Gripping Task			
3	20% MVC (10 sec.)			
	1 min. Gripping Task			
4	20% MVC (10 sec.)			
	1 min. Gripping Task			
5	20% MVC (10 sec.)			
	1 min. Gripping Task			
6	20% MVC (10 sec.)			
	1 min. Gripping Task			
7	20% MVC (10 sec.)			
	30 sec. Rest			
8	20% MVC (5 sec.)			
	30 sec. Rest			
9	20% MVC (5 sec.)			
	30 sec. Rest			
10	20% MVC (5 sec.)			
	30 sec. Rest			
11	20% MVC (5 sec.)			
	2 min. Rest			
12	20% MVC (5 sec.)			
	2 min. Rest			
13	20% MVC (5 sec.)			
	2 min.Rest			
14	100% MVC (5 sec.)			

* Record force for trials 7 and 14. Also record the force level attained if subject was unable to sustain a 20% MVC.

Final Ambient Room Temperature = ____________________

ohara06

II

EVA LIMITATIONS STUDY
SUBJECTIVE EVALUATION FORMS

NAME: ______________________________ SUBJECT CODE: __________
TEST CONDITION: Bare G-0 G-2.3 G-4.3 TEST COND. CODE: __________
TEST CONDUCTOR: ______________________ DATE: __________
COMMENTS:

READ THIS FIRST!

These forms are to be filled out by you--the test subject. They are designed to express your individual thoughts and feelings pertaining to specific areas of the glove tests.

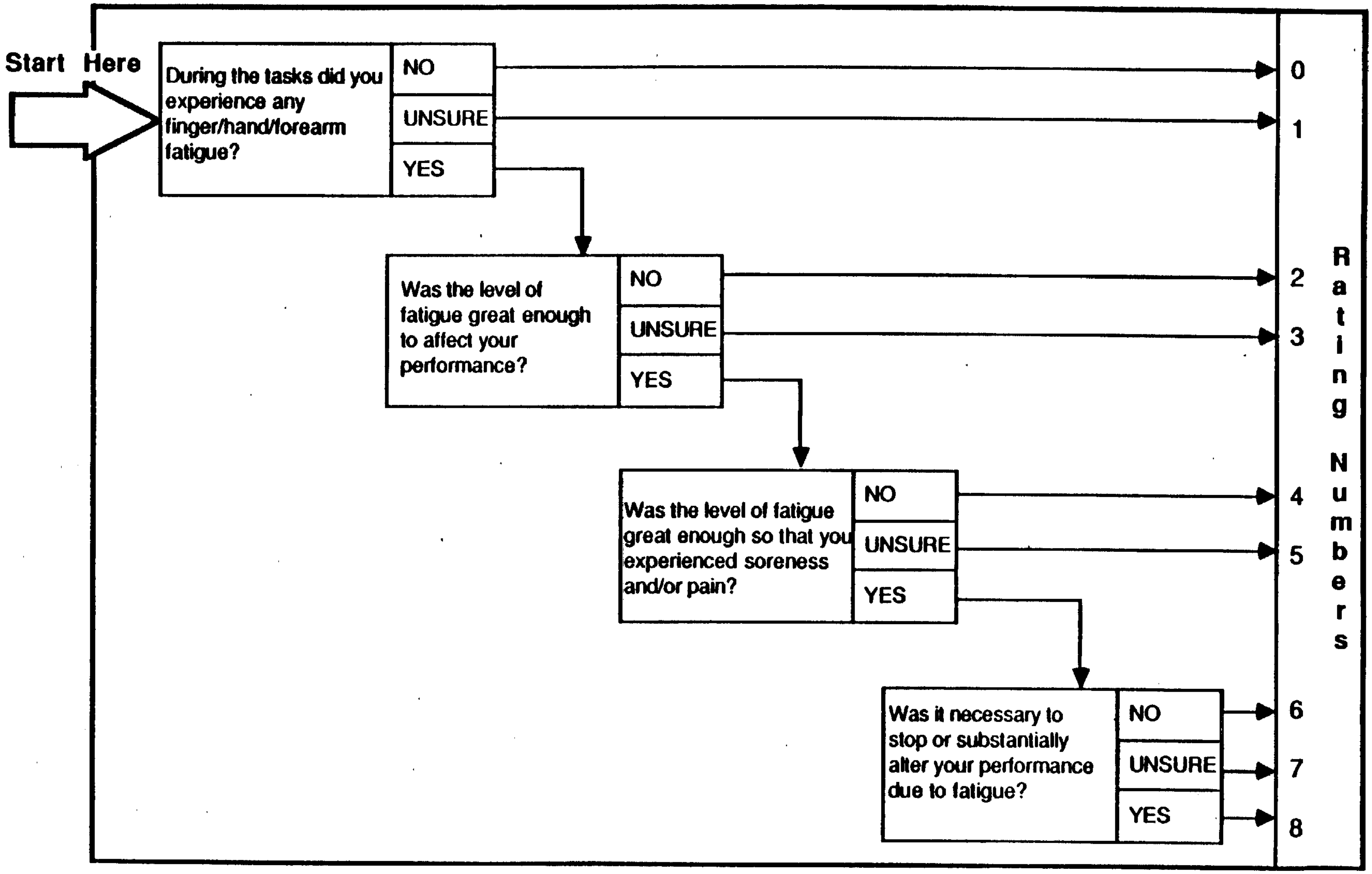
These forms will be given to you by the test conductor on four separate occasions at different times during the glove test.

Read the directions on the top of each page and fill the forms out to the best of your ability. If you have any questions, ask the test conductor for assistance.

GRUMMAN

oharaC2

Directions: Begin your assessment at the large arrow labeled Start Here. Answer the appropriate questions and follow the arrows until you reach the rating numbers on the right side of the table. When you have reached these numbers circle the number corresponding to the arrow you followed and then go on to the next page.

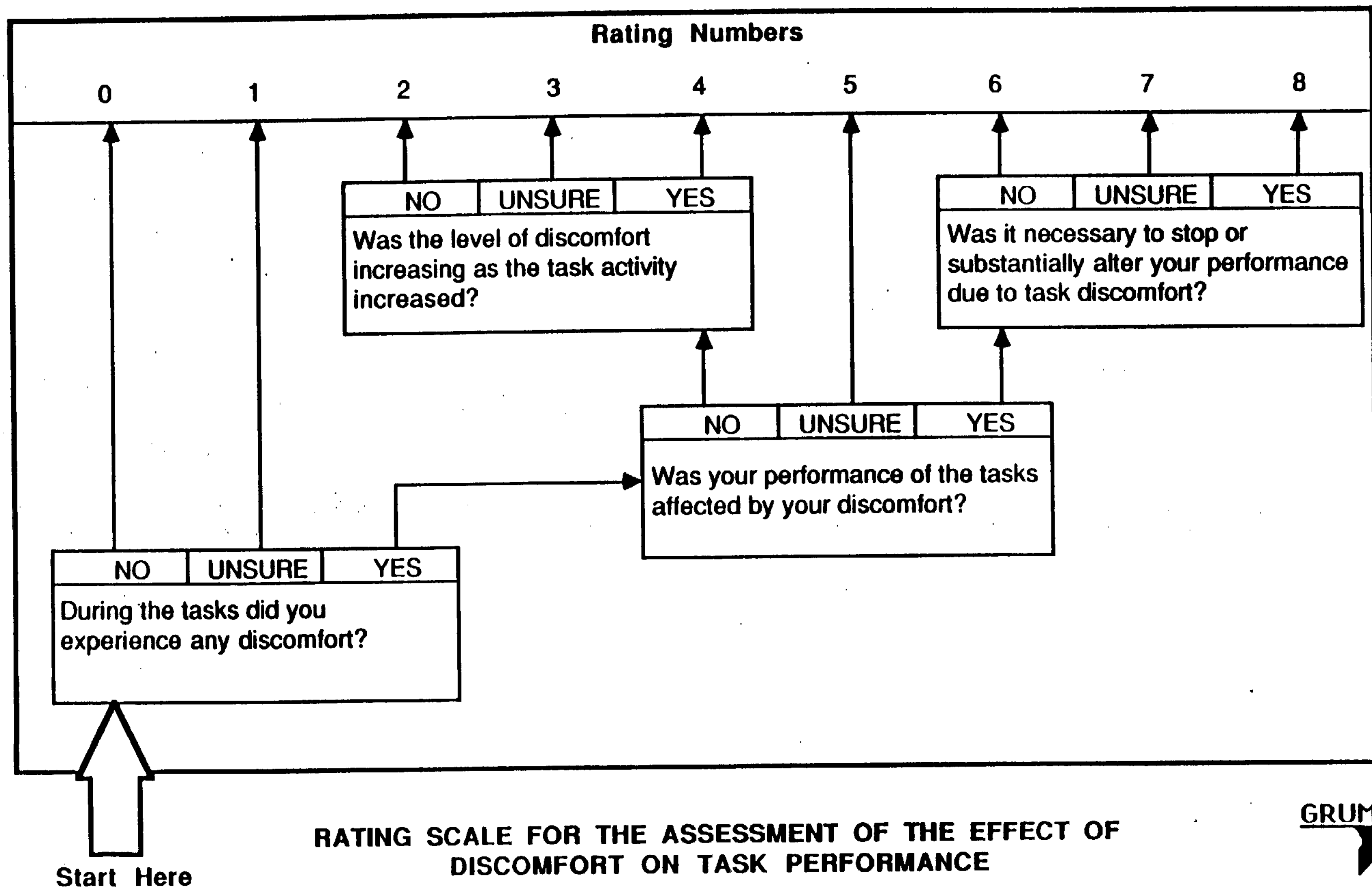


RATING SCALE FOR THE ASSESSMENT OF THE EFFECT OF HAND FATIGUE ON TASK PERFORMANCE

GRUMMAN

ohara01

Directions: Begin your assessment at the large arrow labeled Start Here. Answer the appropriate questions and follow the arrows until you reach the rating numbers at the top of the table. When you have reached these numbers circle the number corresponding to the arrow you followed and then go on to the next page.



RATING SCALE FOR THE ASSESSMENT OF THE EFFECT OF DISCOMFORT ON TASK PERFORMANCE

GRUMMAN

ohara01

FIT AND COMFORT EVALUATION

Directions: For each item no. (column 1) listed in the table below, rate the impact that item has on your ability to accomplish tasks while wearing the gloves. Perform this rating by placing a check in the proper box under column 4. Space has been reserved at the bottom of the table for any additional discomforts that you may have experienced. When you have completed this table, please go the next page.

1	2	3	4		
			IMPACT ON GLOVE PERFORMANCE		
ITEM NO.	NATURE OF DISCOMFORT	DEFINITION	NONE	MODERATE	GREAT
1	CHAFING	To irritate or make sore by rubbing.			
2	CUTTING	To pierce, gash or tear; to scratch or scrape.			
3	PINCHING	To squeeze, cramp or press.			
4	NUMBING	To lose feeling.			
5	HAND TEMPERATURE	Hands/fingers become hot.			
		Hands/fingers become cold.			
6	HAND PERSPIRATION	Excessive hand/finger wetness.			
		Dry feeling of hands/fingers.			
	Specify, if any				
	Specify, if any				

GRUMMAN

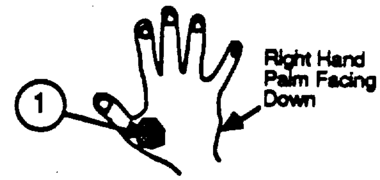
ohara03

Directions: II Refer to table 1 on this page and use the hand sketches to indicate the general area(s) wear specific types of hand discomfort were experienced. Extra space has been left at the bottom of table 1 so that you may indicate any additional discomforts you may have experienced.

Example: If CHAFING was experienced around the right thumb knuckle then label this region using the item no. (1) for CHAFING.

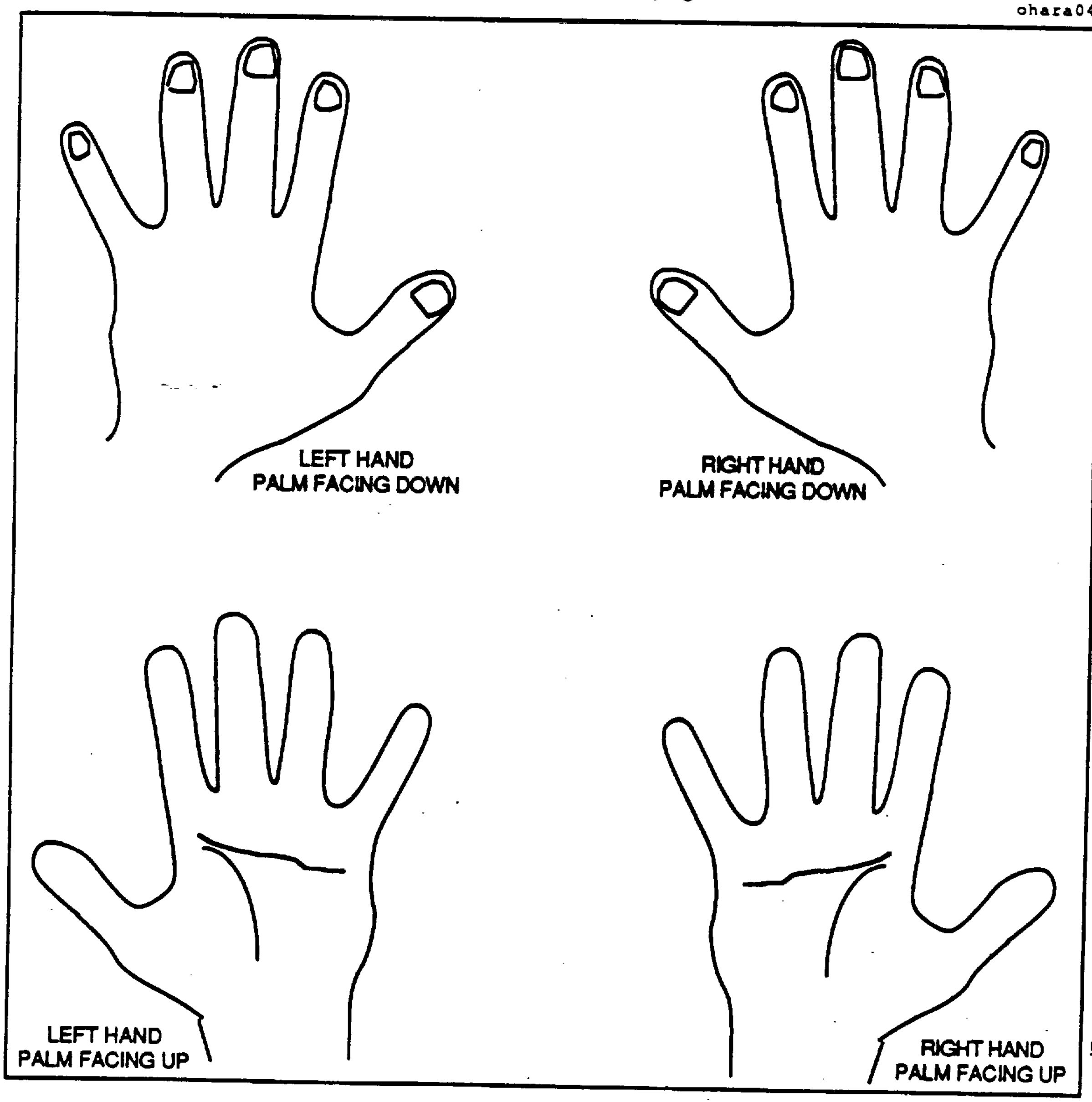
ITEM NO.	NATURE OF DISCOMFORT	DEFINITION
1	CHAFING	To irritate or make sore by rubbing.
2	CUTTING	To pierce, gash or tear; to scratch or scrape.
3	PINCHING	To squeeze, cramp or press.
4	NUMBING	To lose feeling.

Table 1



After completing this form go on to the next page.

ohara04



GRUMMAN

TEST SUBJECT'S COMMENTS AND EVALUATION

Directions: Please comment on specific difficulties you may have experienced during testing. Feel free to use this space to suggests improvements that can be incorporated into the testing procedure and/or test equipment. Be as specific as possible.

COMMENTS:

ohara05

Please return these forms to the test conductor.

Thank you for your cooperation.

GRUMMAN

APPENDIX C
EQUIPMENT DRAWINGS

LIST OF DRAWINGS

- Pegboard Test
- Two-Point Discrimination Test
- Grip Force Control Measuring Instrument
- Tool Stand Fixture
- Object Recognition Rotating Test Stand

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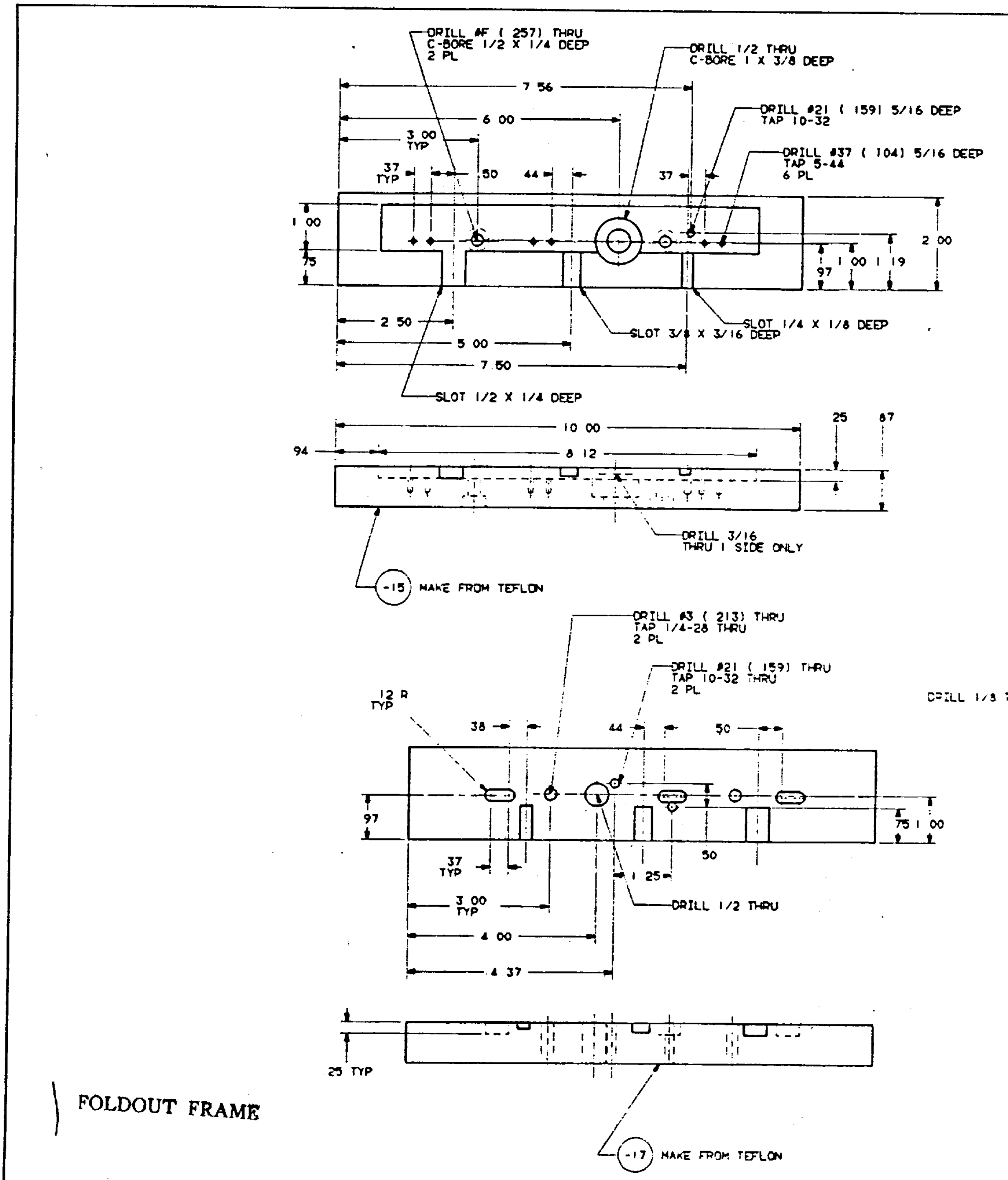

Fig. C-1 Pegboard Test

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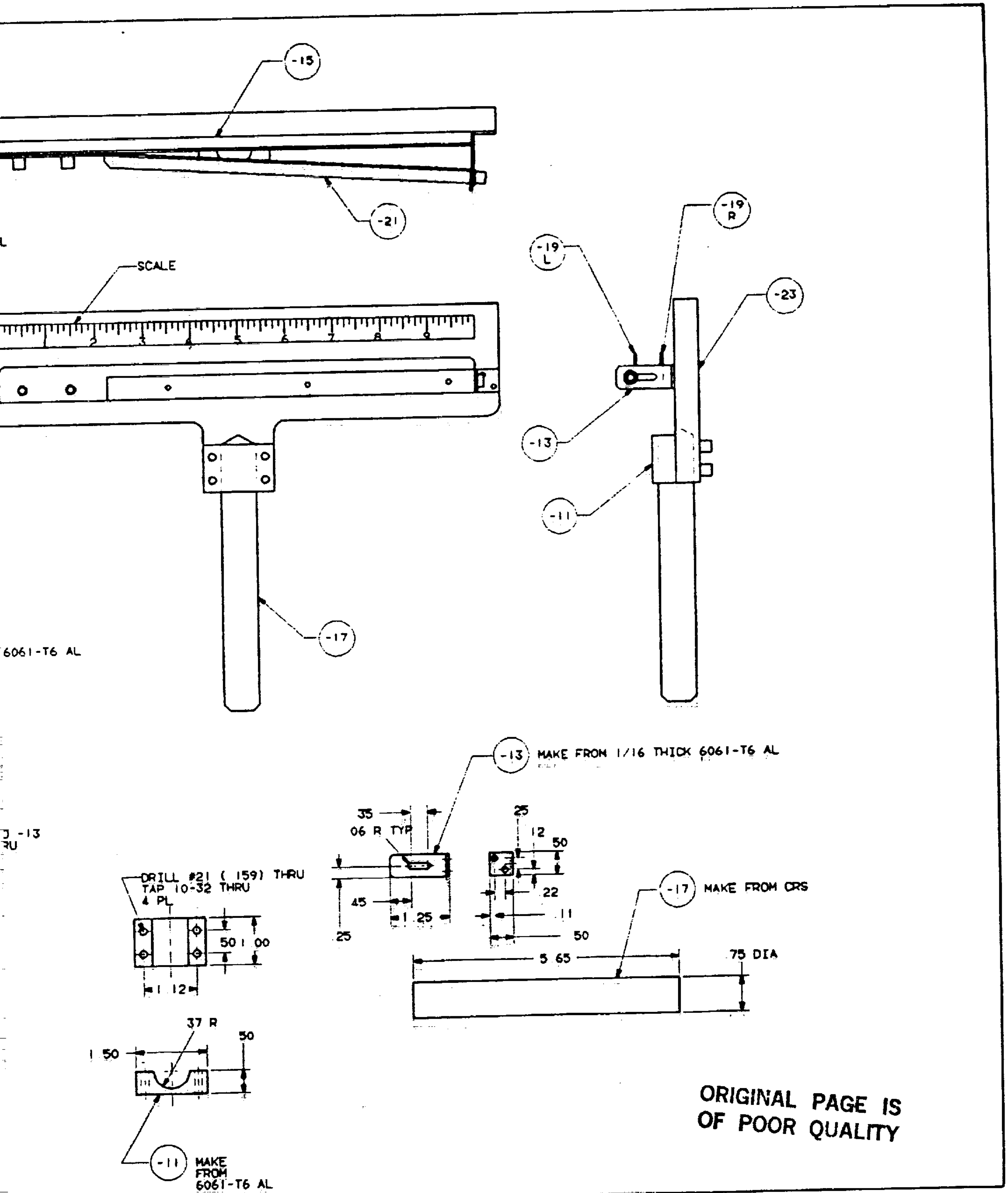

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Fig. C-2 Two-Point Discrimination Test

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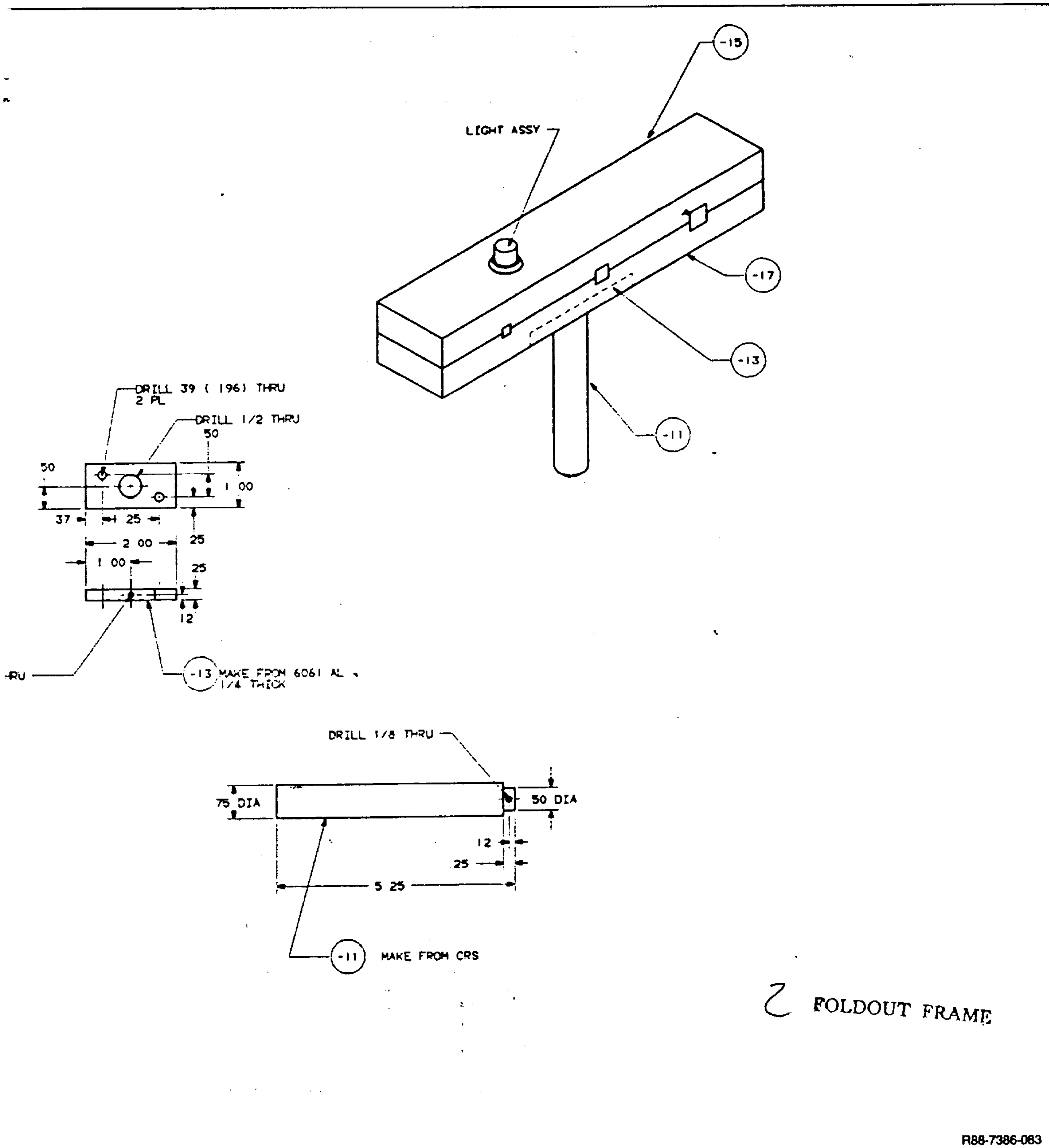

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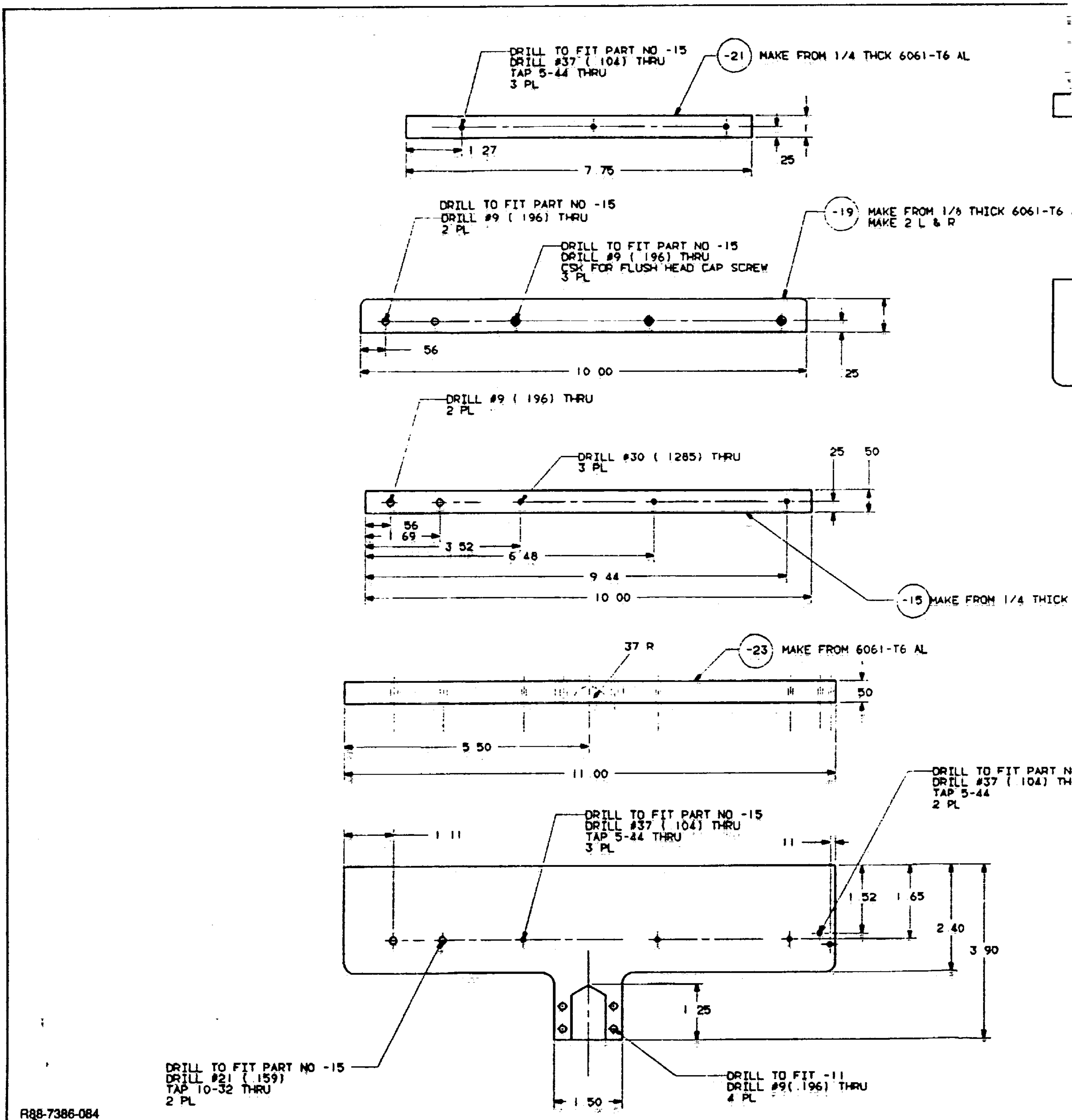

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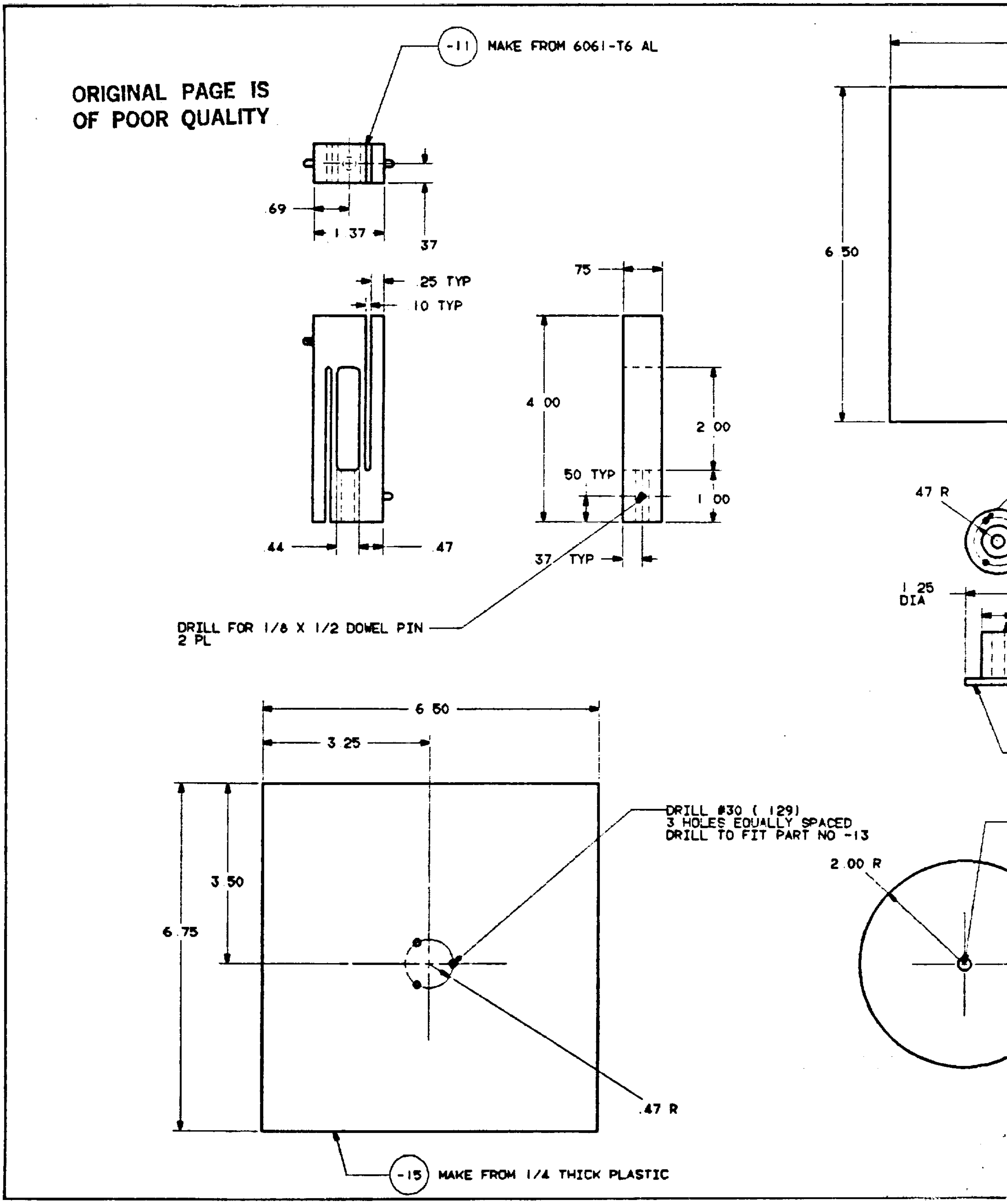

Fig. C-3 Grip Force Control Measuring Instrument

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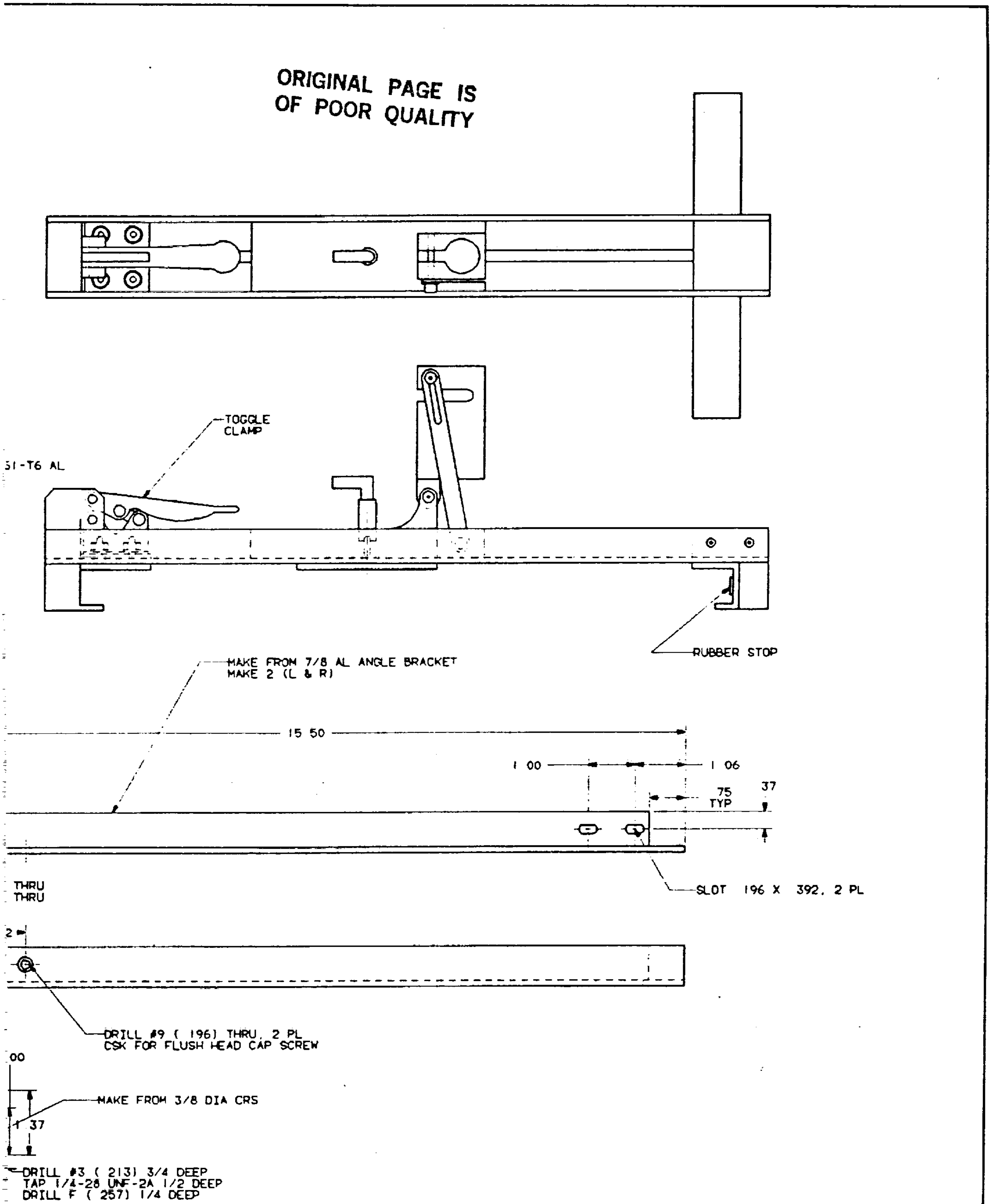

Fig. C-4 Tool Stand Fixture

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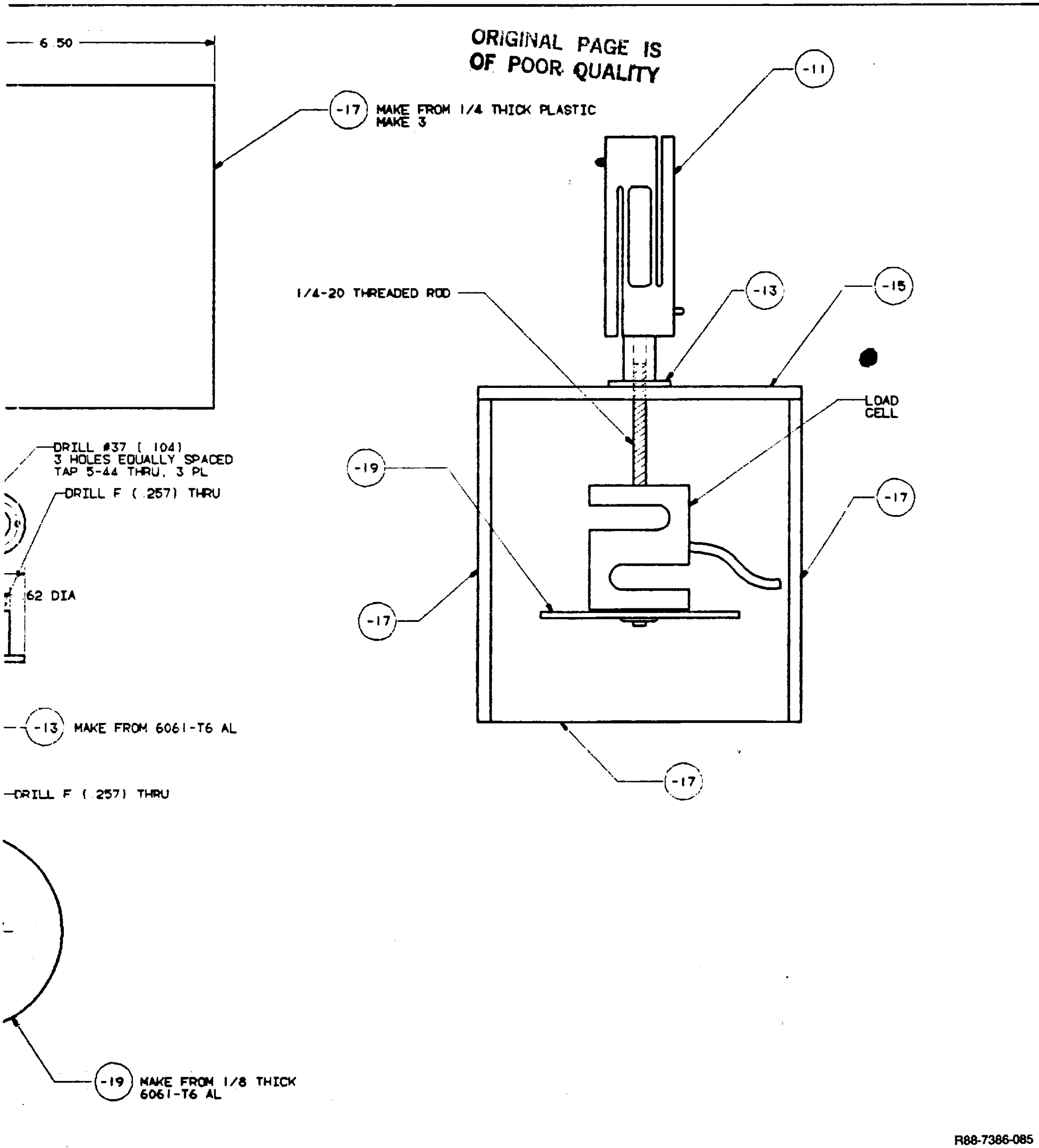

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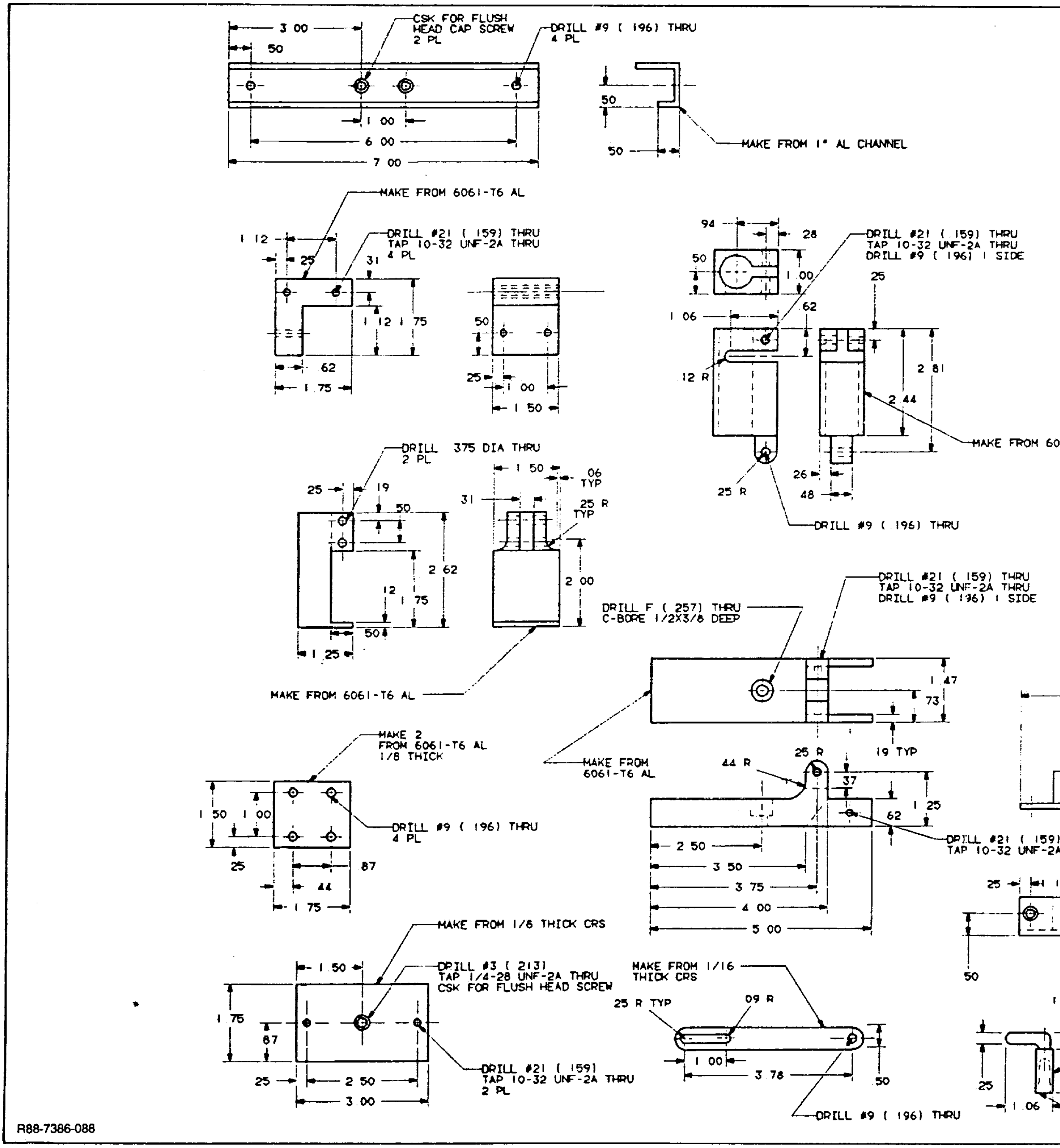

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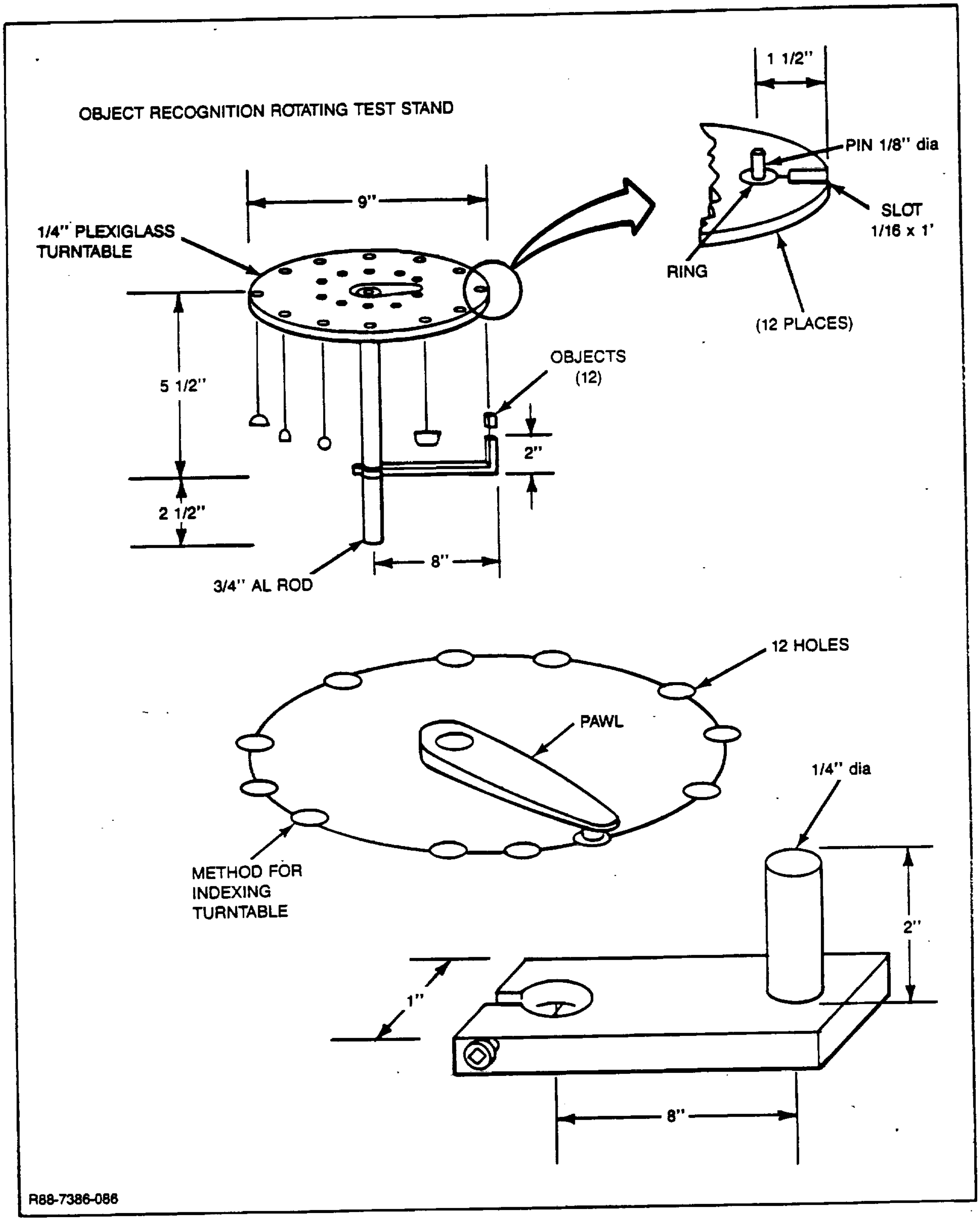

Fig. C-5 Object Recognition Rotating Test Stand

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15. Supplementary Notes

16. Abstract

One of the major problems faced in Extravehicular Activity (EVA) glove development has been the absence of concise and reliable methods to measure the effects of EVA gloves on human-hand capabilities. This report describes the development of a standardized set of tests designed to assess EVA-gloved hand capabilities in six measurement domains: Range of Motion, Strength, Tactile Perception, Dexterity, Fatigue, and Comfort. Based upon an assessment of general human-hand functioning and EVA task requirements several tests within each measurement domain were developed to provide a comprehensive evaluation. All tests were designed to be conducted in a glove box with the barehand as a baseline and the EVA glove at operating pressure. A test program was conducted to evaluate the tests using a representative EVA glove. Eleven test subjects participated in a repeated-measures design. The report presents the results of the tests in each capability domain.

17. Key Words (Suggested by Author(s)) Human Performance, EVA, Gloves, Human Factors, Fatigue, Dexterity, Textile Perception, Strength, Pressure Gloves, EVA Suit, Spare Physiology	18. Distribution Statement

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