INVESTIGATION OF HAND CAPABILITIES UNDER A VARIETY OF PERFORMANCE CONDITIONS AND AN ATTEMPT TO EXPLAIN PERFORMANCE DIFFERENCES

Final Report

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ABSTRACT

Human capabilities such as dexterity, manipulability, and tactile perception are unique and render the hand as a very versatile, effective and a multipurpose tool. This is especially true for environments such as the EVA environment. However, with the use of the protective EVA gloves, there is much evidence to suggest that human performance decreases. In order to determine the nature and cause of this performance decrement, several performance tests were run which studied the effects of gloves on strength, tactile feedback, and range of motion. Tactile sensitivity was measured as a function of grip strength and the results are discussed. Equipment which was developed to measure finger range of motion along with corresponding finger strength values is discussed. The results of these studies have useful implications for improved glove design.

INTRODUCTION

Human capabilities such as dexterity, manipulability, and tactile perception are unique and render the hand as a very versatile, effective and multipurpose tool. This is especially true for environments such as the EVA environment. Protection of hand and facilitation of extravehicular activities (EVA) to be performed by hand are the objectives of glove design. Gloves are the primary protection device for hands while performing EVA. Numerous articles have been published in the area of the effect of gloves on task performance (for example see Bishu and Klute, 1993a, Bishu and Klute, 1993b, Lyman and Groth 1958, and Cochran et al., 1986). The common finding in all these studies has been that gloves reduce both strength and dexterity performance. Possible reasons for this are the reduction in tactile sensitivity when gloves are donned, and reduction in finger range of motion. Verification of these reasons was the driving force behind research performed this summer. The objectives of this research were to ensure that reduction in tactile sensitivity was in fact causing a reduction in gloved performance, and that with gloves there was a reduction in finger range of motion. Another research project pursued this summer was concerned with the relationship between force and endurance. It has been reported by Bishu and Klute (1993a) that pinch strength of persons is consistent across a range of performance conditions. A corollary to this was the question "How long can a person sustain pinch exertions?"

OBJECTIVES

1. To develop a force time relationship for pinch exertions at different postures.
2. To measure the tactile sensitivity at the hand/handle interface under a variety of performance conditions.
3. To develop equipment for measuring finger range of motion and finger strength.

The objectives were achieved through three experiments described below.

Experiment 1: Force endurance for lateral and pulp pinch (Chapman, Bronkema, and Bishu):

In this study, endurance time was evaluated for three types of exertions (grip, pulp pinch, and lateral pinch), at three different postures (extension, neutral, and flexion). Endurance time was expected to depend on the level of exertion, type of exertion, and on the posture adapted.

Method: Six subjects participated in this study. Three levels of exertion (25%, 50%, 100%) were combined with three types of posture (flexion, neutral, and extension) and three types of exertion (pulp pinch, lateral pinch, and grip force) to yield twenty-seven conditions. The devices used to measure these various strengths were the hand dynamometer and the pinch gauge. Initially the maximal exertions were determined for all the subjects on the first day. The test trials started on the following day. The exertion force for the day was calculated with respect to the maximal exertions. The subjects performed two trials per day, with the order of presentation being randomized. A trial consisted of subjects exerting their condition of the day until they quit voluntarily. The endurance time was recorded and used as a primary dependent variable in analysis.

Results: The data was analyzed with respect to exertion force, and endurance time using SAS software. All the main effects were significant for the endurance force, while exertion

level, expressed as a percentage of maximum voluntary contraction, was the only significant effect. Figure 1 shows the histogram of the type of exertion effect. The grip strength is considerably greater than the two pinch strengths tested here. Figure 2 shows the histogram of the posture effect on exertion. The force exerted at the extended posture of the wrist appears to be more than that exerted at the flexed posture. Figure 3 shows the endurance time plot. As expected, the time the contraction was maintained is the least at 100% exertion level and the most at 25% exertion level.

Discussion: Perhaps the most interesting finding of this experiment is the lack of posture and type of exertion effect on endurance time. A posture effect was definitely expected as was a posture*exertion level interaction. The results suggest that the physiological mechanisms which cause reduction in capabilities due to factors such as posture, gloves, etc. are independent of the mechanisms which cause muscular fatigue. This is a big conjecture and, if proven, has ramifications for the designers. However, the results obtained here suggest just this.
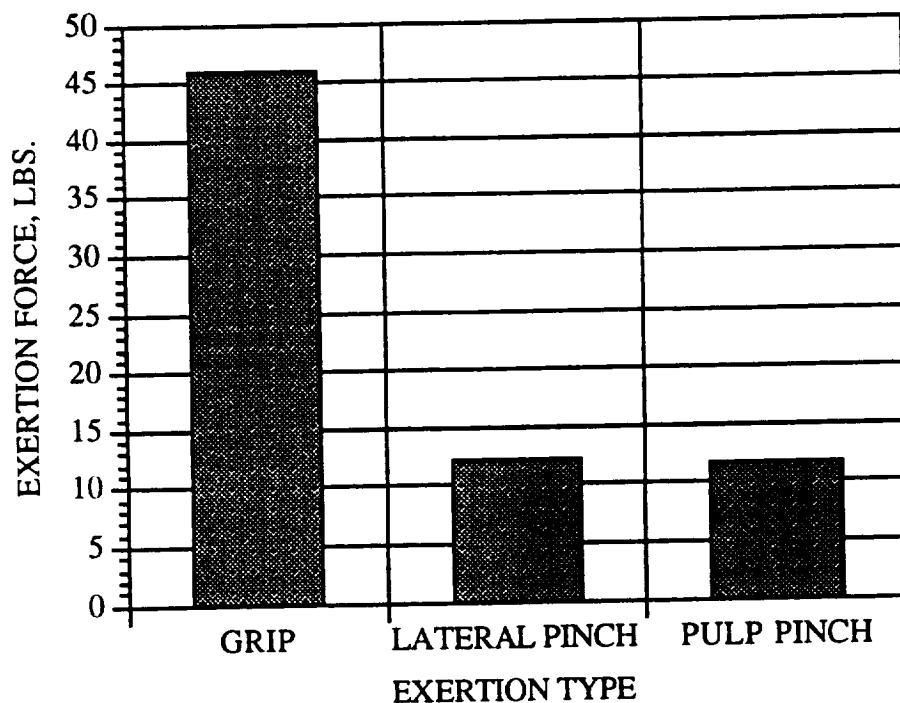

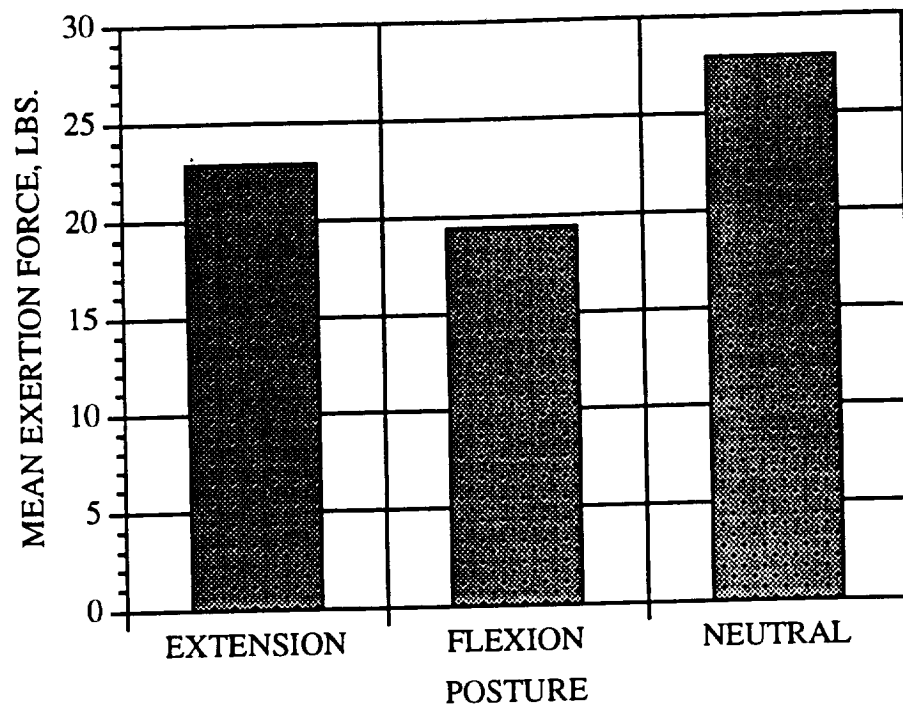Figure 1.- Exertion type effect on exertion force.
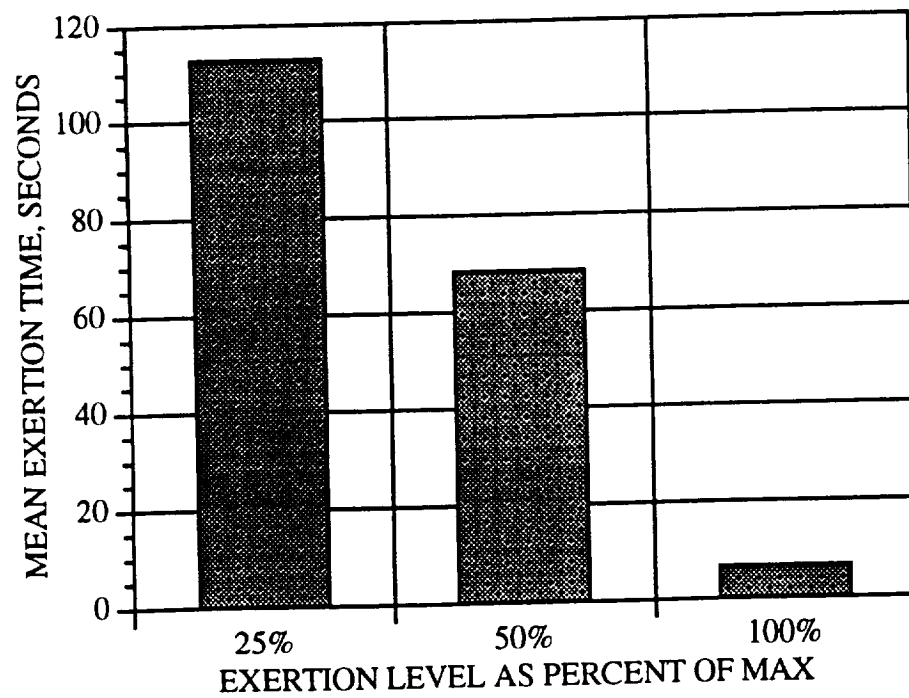
Figure 2.- Posture effect on exertion force.

Figure 3.- Exertion level effect on time.

Experiment 2: Tactility as a function of grasp force: the effects of glove, pressure and load (Garcia, Bronkema, and Bishu).

One of the reasons for reduction in performance when gloves are donned is the lack of tactile sensitivity. It was argued that grasping force for a weight to be grasped will be a function of the weight to be lifted and the hand conditions. It was further reasoned that the differences in grasping force for various hand conditions will be a correlate of the tactile sensitivity of the corresponding hand conditions. The objective of this experiment, therefore, was to determine the effects of glove type, pressure, and weight of load, on the initial grasping force and stable grasping force. It was hypothesized that when a person grasps an object, he grasps very firmly initially and then releases his grasp slightly as he realizes what force is needed to maintain a steady grasp. This would seem to be particularly true when a person is wearing a glove and has lost some of his tactile sensitivity and force feedback during the grasp. Therefore, the ratio of initial force and stable force as well as the stable force itself would represent the amount of tactile adjustment that is made when picking up an object, and this adjustment should vary with the use of gloves.

Apparatus: To measure the grasping force, a dynamometer was fabricated and is shown in Figure 4. It consisted of two steel halves, which, when placed together, formed the same elliptical shape of the grab bar on the shuttle payload bay. A small plate was attached to the bottom of the device, so that weights could be added as needed. Between these two halves, at the top and bottom of the device, load cells were placed to measure the horizontal forces applied by the hand along the long axis of the cross section. The output of the load cells was channeled through a real-time data recording system. The data was analyzed using the SAS.
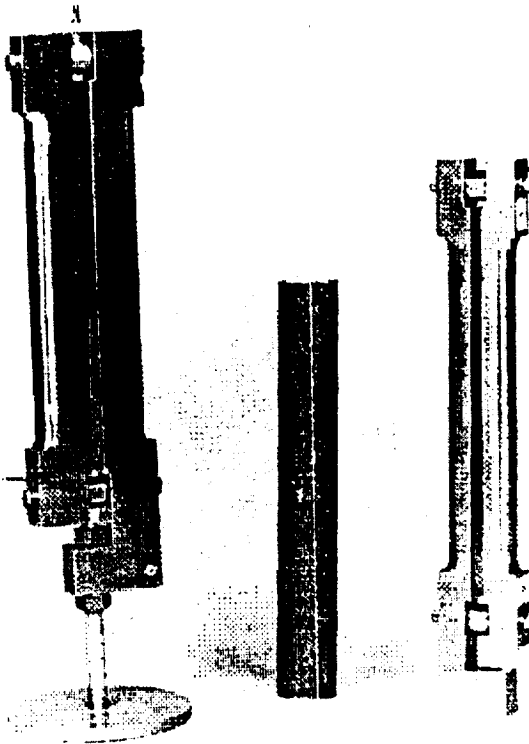
Figure 4.- Dynamometer fabricated and used for this experiment.

Method: The actual performance tests were performed inside a glove box. The independent variables of the experiment were glove type, pressure, load and gender as shown below:

Glove type:	Shuttle, Advanced, and Barehanded
Pressure:	0 PSID, 4.3 PSID, and 8.3 PSID
Load:	3.5 lbs, 8.5 lbs, and 13.5 lbs
Gender:	Male and Female

Eight subjects, four males and four females, participated in this study. For each subject appropriate hand and arm anthropometric dimensions were taken, after which each of the 18 trials were performed, allowing three minutes of rest time between trials. The trial began with adjusting both the weight of the unit and the pressure of the glove box. The subject then donned the glove and adjusted the placement of the grip device so that it was comfortable. After resetting the computer, the subject was asked to grasp and hold the object as he/she normally would of that size and weight. Following a 20 second holding period, the subject was asked to release the grasp as slowly as possible, so that the device

would gradually slip through their hands. The order of the trials was randomized across all the conditions.

Results: Peak force, stable force, and the ratio of peak to stable force were the main dependent variables. Analyses of variance was performed on the data. Among the main factors, load effect and gender effect were significant. Figure 5 shows the plot of the gender effect. Females tended to have a lower stable force than the males. It is possible that the males were over controlling. Figure 6 shows the plot of the load effect. As the load increases so does the grasp force. This was expected. The ratio, although not significant, seems to reduce with increasing load.

Discussion: The results of the study were somewhat counter-intuitive since the only significant effects on the peak and stable grasp force were caused by gender and the weight of load lifted. Neither the gloves nor pressure altered these forces when compared to a barehanded condition as was suspected prior to the test. One reason for this could be that gloves can actually help in holding if they have a large enough coefficient of friction. It is possible that gloves facilitate in holding, due to coefficient of friction while they deter in peak grasp strength. The absence of pressure effect led to the next experiment being performed outside the glove box, and with larger number of conditions.

Experiment 3: Tactility as a function of grasp force: Effects of glove, handle size, orientation, and load (Garcia, Bronkema, and Bishu).

The objective of this experiment was to determine the effects of gloves, handle size, handle orientation, and load lifted on grasp force. The working hypotheses were that grasp force would be a function of all the above mentioned factors.

Method: The same set-up as experiment 2 was used here, but with one exception. A possible reason for the lack of glove and pressure effects in experiment 2 could have been the feedback provided by the visual cue in holding. Therefore, to avoid the visual cue, the subjects lifted and held the load as shown in Figure 7. The other difference was that this experiment was performed outside the glove box. The independent factors were 4 levels of glove (advanced, shuttle, meat packing and bare hand), 3 levels of load (5, 10, and 15 lbs.), 2 levels of orientation (transverse and lateral), and 2 levels of size (large and small). There were 48 conditions in all and 10 subjects (5 male and 5 female) participated in this experiment. The order of presentation was randomized across each subject. The procedure was identical to experiment 2. Stable force, peak force, and ratio of peak to stable force were the dependent measures for analyses. In addition to these, the maximum grasp force at each condition in the lateral orientation was also recorded to determine if maximum grasp was different from holding.

Results: Due to space restrictions, summary analyses are discussed here. The complete report with detailed analyses will be published as a NASA Technical Paper. Among the main factors load, gender, handle orientation, and glove effects were significant. Load effect was similar to Figure 6 with increasing grasp force for increasing loads. The gender effect was again similar to Figure 5 with the female grasping force being 70% of the male
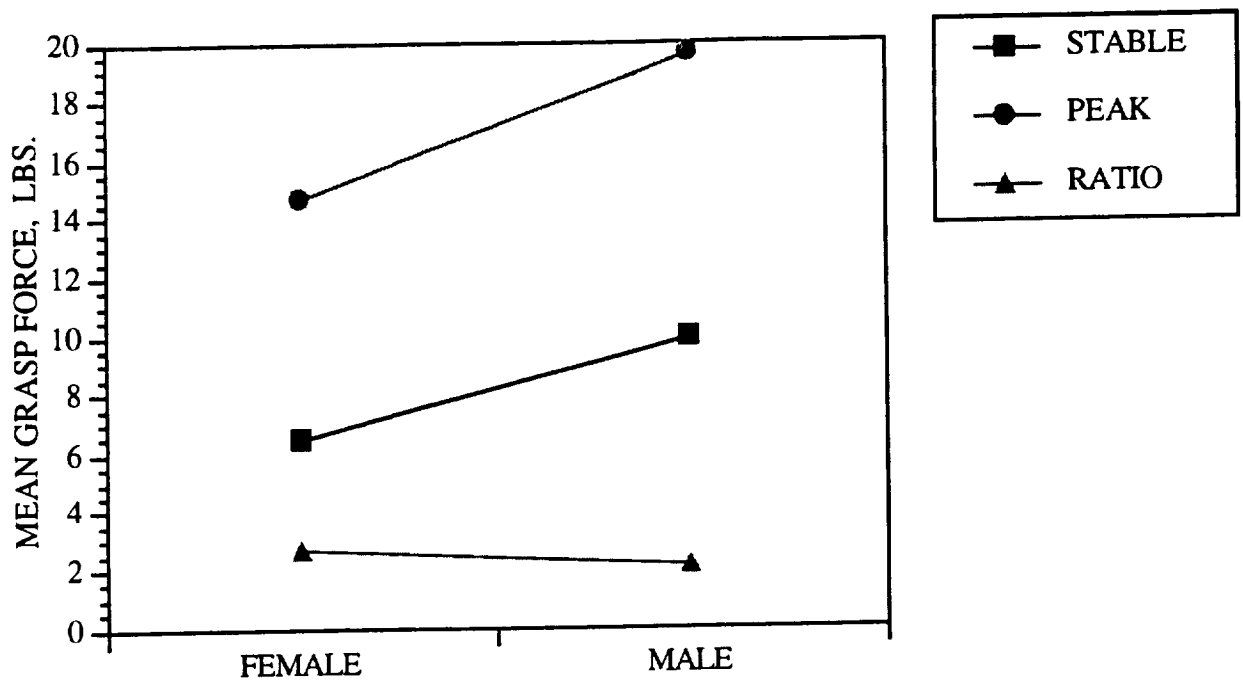
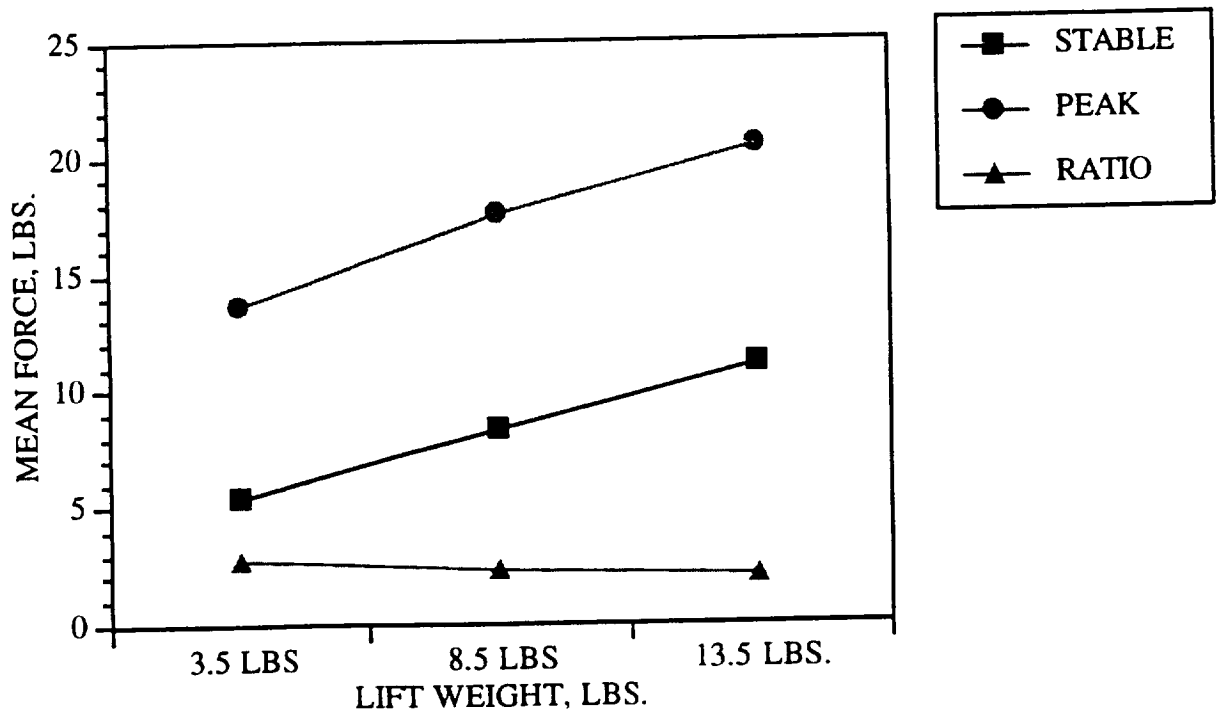Figure 5.- Gender effect on mean grasp force.

Figure 6.- Load effect on mean grasp force.

Figure 7.- Set-up for Experiment 3.

grasping force. Figure 8 shows the glove effect and it is interesting to note that barehanded and meat packing gloves had significantly larger grasp force than the shuttle and advanced developmental glove. The orientation effect is shown in Figure 9. The lateral position had a greater grasp force than the transverse position. Figure 10 shows the plot of the glove effect on the maximum grasp force. It is very interesting to note that Figures 8 and 10 are similar with bare hand and meat packing showing much higher forces than the advanced and shuttle gloves. The implications of this similarity are far fetched.
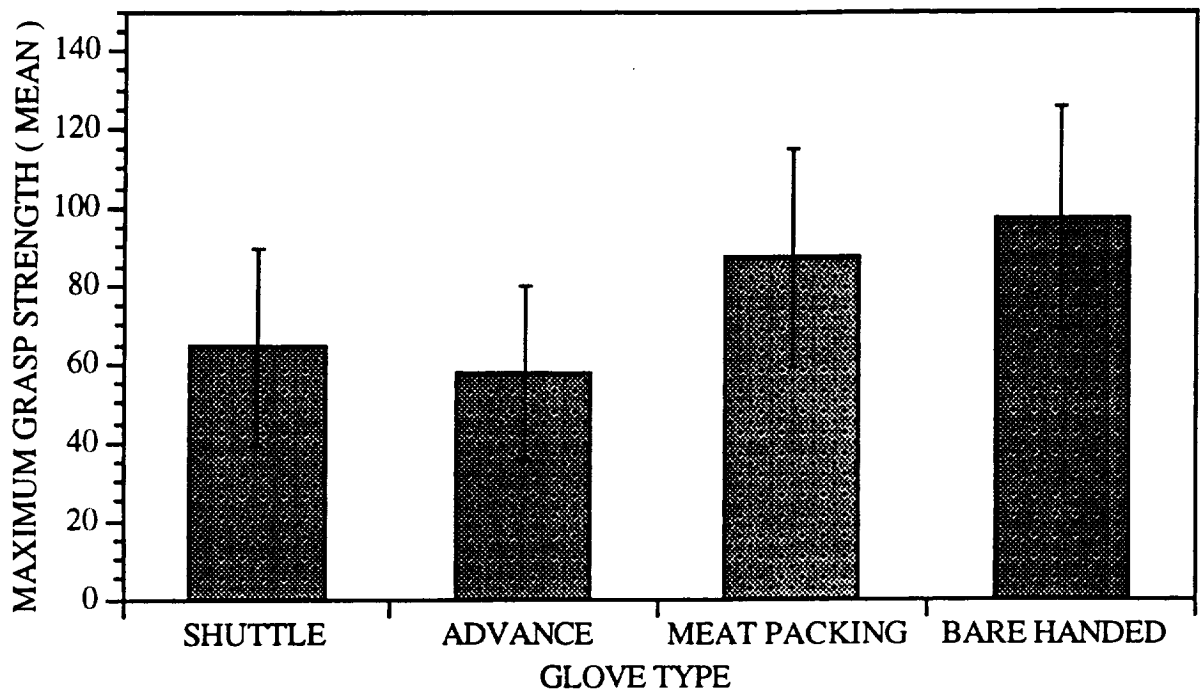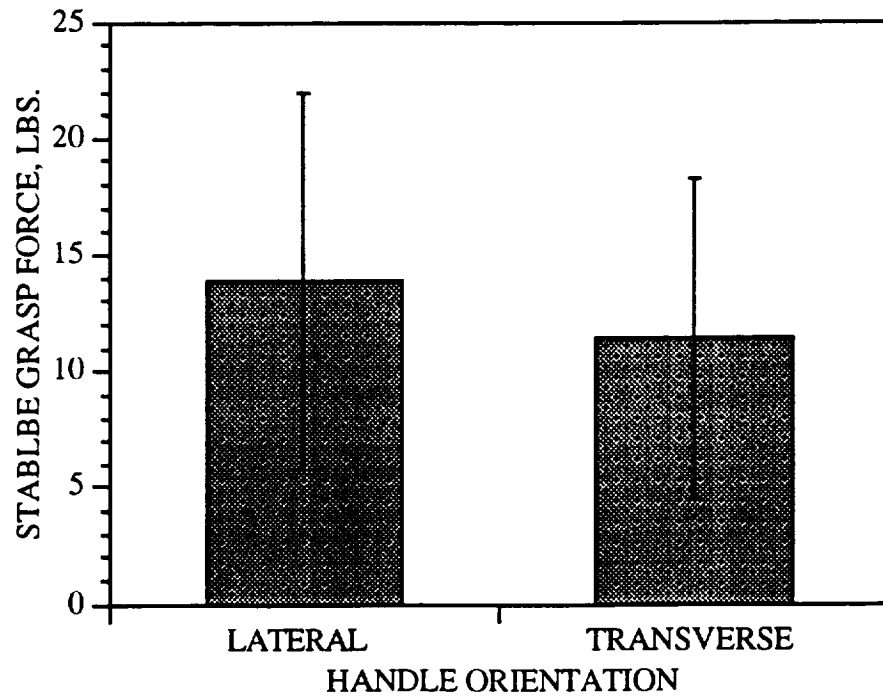
Figure 8.- Glove effect on maximum grasp strength.

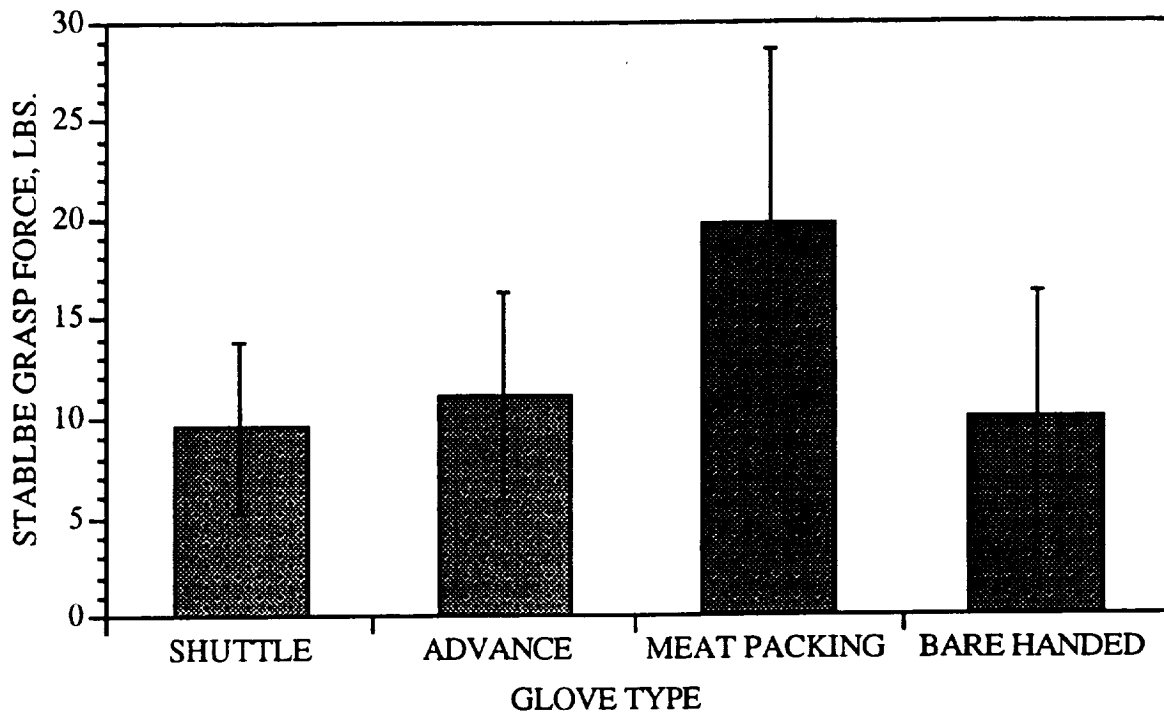Figure 9.- Handle orientation effect on stable grasp force.

Figure 10.- Glove effect on stable grasp force.

Overall Discussion: It is evident that friction at the glove handle interface impacts the grasping force. This is seen by the reduced grasp force with advanced glove and shuttle glove. There are also indications that the effort exerted by the lower arm musculoskeletal system may be the same for a range of variations in the wrist/fingers/handle configurations. This is evidenced by lack of posture effect in experiment 1, and similarity between Figures 8 and 10. Similarity in glove effect between maximal grasp and stable grasp forces for the three weights tested in experiment 3 indicates that exertion by the musculoskeletal system at the lower arm may be the same, although the force registered by the load cell varied. More research is definitely needed. If this be so, then a tactility index based on the grasp force is possible.

Experiment 4: Isometric strength and range of motion measurement of fingers (Fletcher, Bronkema, and Bishu)

One possible reason for lower dexterity with gloves could be the reduction in finger strength and finger range of motion. It is possible that gloves change the distance between digits and the apparent distance within digits. Considerable need exists for determining the finger strengths and finger range of motion (ROM). The objective of this experiment to design a device to measure the finger strength and ROM.

Apparatus: A literature review revealed the absence of any device for finger strength measurement. Therefore, a device had to be designed and fabricated. The design had to have the capability of restraining digits whose strength was not being measured, and have the capability of motion and strength measurement for the unrestrained digit. A device as shown in Figure 11 was designed and fabricated.

Method: Six subjects participated in this experiment. The isometric strength of the four digits and the metacarpal joint was measured at five different finger angles (0, 15, 30, 45, and 60 degrees). The measurements were done in six different hand conditions (bare hand, advanced glove at 0 psid, advanced glove at 4.3 psid, advanced glove at 8.3 psid, shuttle glove at 0 psid, and shuttle glove at 4.3 psid).

Currently the data is being collected. The complete report of this experiment will be published as a NASA Technical Paper.
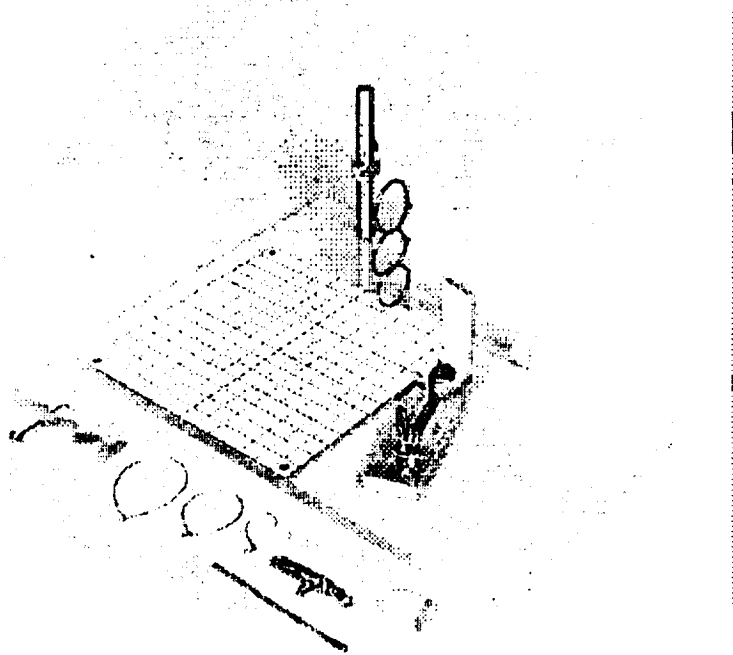

Figure 11.- Device used to measure finger range of motion and strength.

Experiment 5: Ergonomic evaluation of EVA tools (Bronkema and Bishu).

The objective of this project which is currently in progress is to perform an ergonomic evaluation of EVA tools. A short list of EVA tools for evaluation was compiled from astronaut briefings and other NASA documents. From this list, the wrist tether hook was chosen for evaluation, a hook which has historically been difficult and fatiguing to use. Two processes of evaluation were chosen and are being used. The first is a performance evaluation in which six different types of tether hooks are used, ranging in age from the Apollo program to some of the most current developmental hooks. The primary measure of performance in this experiment will be the amount of time needed to perform each of four different types of hooking tasks. The tasks were chosen as a result of suggestions from astronauts and WETF safety divers, and are typical of tasks performed on EVA's. The second process consists of a questionnaire which is administered to each subject following the performance test. It is in a paired comparison format and is designed

to determine the subjects' personal preference of which tools are easiest to use, least fatiguing, and require the least amount of force for activation.

When the data is complete, it will be analyzed to determine the effects that hook, hooking task, gender, and hand size have on performance. Actual performance values will be compared to the preferences voiced in the questionnaire to determine consistencies or inconsistencies in the two types of evaluations. It is expected that a generic procedure for ergonomic evaluation will emerge from this project.

REFERENCES

Will be furnished on request.