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A Comparison of Hand Grasp Breakaway Strengths and Bare-Handed Grip Strengths of the Astronauts, SML III Test Subjects, and the Subjects From the General Population

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National Aeronautics and
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ABSTRACT

Astronauts have the tasks of retrieving and deploying satellites and handling massive objects in and around the payload bay. Concerns were raised that manual handling of such massive objects might induce loads to the shuttle suits exceeding the design-certified loads. The Crew and Thermal Division of NASA JSC simulated the satellite handling tasks (Satellite Manload Tests I and III) and determined the maximum possible load that a suited member could impart onto the suit. In addition, the tests revealed that the load to the suit by an astronaut could be calculated from the astronaut's maximum hand grasp breakaway strength.

Thus, this study was conducted to document the hand grasp breakaway strengths of the astronauts who were scheduled to perform EVA during the upcoming missions. In addition, this study verified whether the SML III test results were sufficient for documenting the maximum possible load. Finally, an attempt was made to predict grasp strength from grip strength and hand anthropometry.

The hand grasp breakaway strengths of 18 astronauts were documented and compared against the strengths of the 5 SML III test subjects and 28 subjects from the general population. Based on the results from this study, the SML III test results were deemed sufficient to document the maximum possible load on the suit. Finally, prediction of grasp strength from grip strength was not as accurate as expected. Hence, it was recommended to collect grasp strength from the astronauts in order to obtain accurate load estimation.

INTRODUCTION

With the advent of the Shuttle's extravehicular activities (EVA), astronauts are entrusted to perform tasks such as satellite deployment and retrieval as well as handle other massive objects in and around the payload bay. During such demanding tasks, the mission specialist must perform these tasks manually. Concerns were raised that manual handling of such massive objects might induce loads to the shuttle suits exceeding the design-certified loads. The following paragraph enumerates the reasons for these concerns.

Prior to Mission 51-A (November 1984), man-load specification values were based on the assumption that the suit man-loading was induced internally (such as from bending, reaching, or pushing within the suits). During the flight mission 51-A, crewmembers were required to recover the 33,400 N (7,500 lb) mass Westar/Palapa satellite. This recovery marked the first use of crewmen in portable (fixed) foot restraints (PFR) to handle massive objects during an EVA. During that mission, concerns were raised that the suit certification did not address such a scenario. Similarly, during mission 51-I (August 1985), crewmembers were required to retrieve and deploy the massive 67,000 N (15,000 lb) LEASAT satellite. One of the crewmembers remarked during debriefing that a significant amount of loading was transferred through the suit from the satellite to the foot restraints. Based on this information, concerns were again raised that the suit might be subject to excessive loads when the satellite was handled by the crewman in PFRs or when the satellite was moving away from the crewman.

As a result of these concerns, the Crew and Thermal Division of NASA JSC conducted the Satellite Man Load (SML) test I to quantify the loads imparted to the suit during satellite handling. The subjects wore a pressurized (4.3 psi.) suit and were restrained in a PFR. Since the subjects had to wear pressurized suits and perform tests that might lead to tearing of the suits, only two non-crewmembers were used as subjects. The subjects grasped a standard EVA handhold bar which was attached to a hydraulic cylinder via a trapeze mount which used two parallel ropes to support the bar. The handhold bar was pulled away from the subjects at constant rates

(7.6, 12.7, 17.7, and 22.9 cm/sec) while the subject attempted to retain the bar. The arm span sizing of the suit was also adjusted during the test. The total resistance of the load and the load imparted to the suit were monitored and gathered.

The results from the SML I showed that a significant amount of loading on the suit could occur as a result of satellite handling. The results also showed that the maximum load on the handhold bar would be limited by the maximum grasping capacity of the subjects. Hence, it was hypothesized that the maximum loading on the suit by an astronaut during an EVA could be determined solely by measuring the astronaut's maximum hand grasp breakaway. Based on this hypothesis, the SML II test (Fuji, 1989) was conducted to obtain the maximum hand grasp strength from the SML I test subjects and from 32 astronauts. It was hoped that the amount of load imparted by an astronaut onto the suit could be predicted by comparing the astronaut's grasp strength to those of the SML I test subjects. The results from SML I and II indicated that the EVA handhold bar load and the grasp breakaway strength were highly correlated and linearly related to each other, with a ratio of 1:1.

While both SML I and SML II tests provided useful information, the usefulness of the data, particularly the SML I test data, was rather limited. Primarily, with only two subjects participating in the SML I test, concerns were raised as to whether the data would be adequate to draw conclusions. Secondly, while SML I measured the loads on the glove, arm, and the Hard Upper Torso (HUT) assembly, the load transferred to the Lower Torso Assembly (LTA) was not measured. Hence, a third test, SML III, was initiated (Pantaleano, et al., 1992). Five non-crewmembers served as subjects. Since the primary objective was to measure the maximum possible load, only those with strong physical attributes (weight: 90.9 kg or more; height: 183 cm or more) were selected. At the completion of SML III, this study was initiated so that the results from the SML III test subjects could be compared to the STS-49 crewmembers and others who were scheduled to perform EVA during the mission.

OBJECTIVES

The primary objective of this study was to document the grip[1] and grasp[2] strength capabilities of the astronauts and the five SML III test subjects. It was intended, as in the SML II test, that by comparing the strength capabilities of the astronauts to those of the test subjects, it would be possible to pre-determine an appropriate sizing of the suit for each astronaut such that the loading on the suit could be kept well within the safety limits.

The second objective of this study was to determine whether the SML III test subjects and the astronauts were strong enough to record the maximum possible load on the suit. It was not certain whether the SML III test subjects and the astronauts were stronger than the subjects from the general population. Hence, the individual strength capabilities of the SML III test subjects and the astronauts were compared against the individual strength capabilities of the subjects selected from the general population. The selection of subjects from the general population included those who were physically strong. If the individual strength of a subject from the general population were greater than the SML III subjects and the astronauts, then that information could be used to set the design guidelines for the suits.

[1]Grip strength: measurement of hand strength to grip a handle or an object. Grip strength involves a sustained (isometric) concentric muscle contraction. After the initial part of gripping, muscle length remains relatively constant.

[2]Grasp strength: measurement of hand strength while grasping an object which is in motion. Grasp strength involves dynamic eccentric muscle contractions. Muscle length varies during an eccentric contraction.

The third objective of this study was to verify whether the subjects within the astronaut group and the SML III test subject group were similar to the subjects from the general population as a group. In addition, while there are several references on the differences in grip strength between males and females and between right and left hands, there were no references on the differences in grasp strength. Hence, it was intended to document the grasp and grip strength differences between males and females and between right and left hands.

The fourth objective of this study was to determine a regression-based model to predict the grasp breakaway strength in terms of grip strength and one or more hand anthropometric measurements. While isometric grip strength exertion involves concentric contraction of the hand muscles, the handgrasp breakaway strength exertion involves eccentric contractions. During eccentric contractions, the likelihood of straining the muscles is more than during concentric contractions. In addition, eccentric exertions are more fatiguing than isometric exertions. Furthermore, the grip strength data can be quickly collected from the astronauts, since the dynamometer is light-weight and portable. For these reasons, a regression model was attempted to estimate the grasp breakaway strengths from the hand dimensions of the astronauts and their maximum grip strength capabilities.

METHODOLOGY

SUBJECTS

Initially, 53 subjects participated in this study. Among those 53 subjects, two subjects' data were not included in the final analysis due to data collection errors. With the exception of these two subjects, the subject population included 18 astronauts, 5 SML III test subjects, and 28 subjects from the general population. The astronaut sample included 15 males and 3 females; the SML III test group had 5 males and no female; and the general sample included 9 males and 19 females. Thus, there were 22 females and 29 males (see Table 1). Table 2 shows the age, height, weight and other anthropometric characteristics of the subject population.

Table 1. Subject Pool

Subject Pool	Male	Female
Astronaut	15	3
SML III	5	0
General	9	19

Table 2. Subject Characteristics

Anthropometric Variables	Mean	Standard deviation	Min.	Max.
Age (yrs)	32.6	6.44	20.0	55.0
Weight (kg)	72.8	16.30	39.5	103.7
Height (cm)	173.5	9.17	143.4	188.4
Length (cm)				
Hand	18.5	1.40	14.9	22.4
Palm	10.5	0.83	8.5	12.3
Forearm	25.5	2.15	19.7	30.7
Upper arm	37.3	2.56	30.0	43.0
Circumference (cm)				
Wrist	16.2	1.71	12.5	18.9
Forearm	26.3	3.48	20.5	32.0
Upper arm	28.0	4.15	20.9	35.2

APPARATUS

A standard hand dynamometer (Lafayette Instrument Co., Lafayette, IN) was used to measure the hand grip strength (Figure 1). The dynamometer was mounted on gimbals so that the subjects could keep their hands in a neutral position. The neutral position in this experiment was arrived at by having the subject's forearm supinated 90 degrees and with the elbow joint at 90 degrees. The hand grasp breakaway strength was measured by using a specially constructed pneumatic powered apparatus (Figure 2). An EVA hand rail was attached to a pneumatic cylinder via a load cell. The load cell measured the force at which the pneumatic cylinder pulled the handrail

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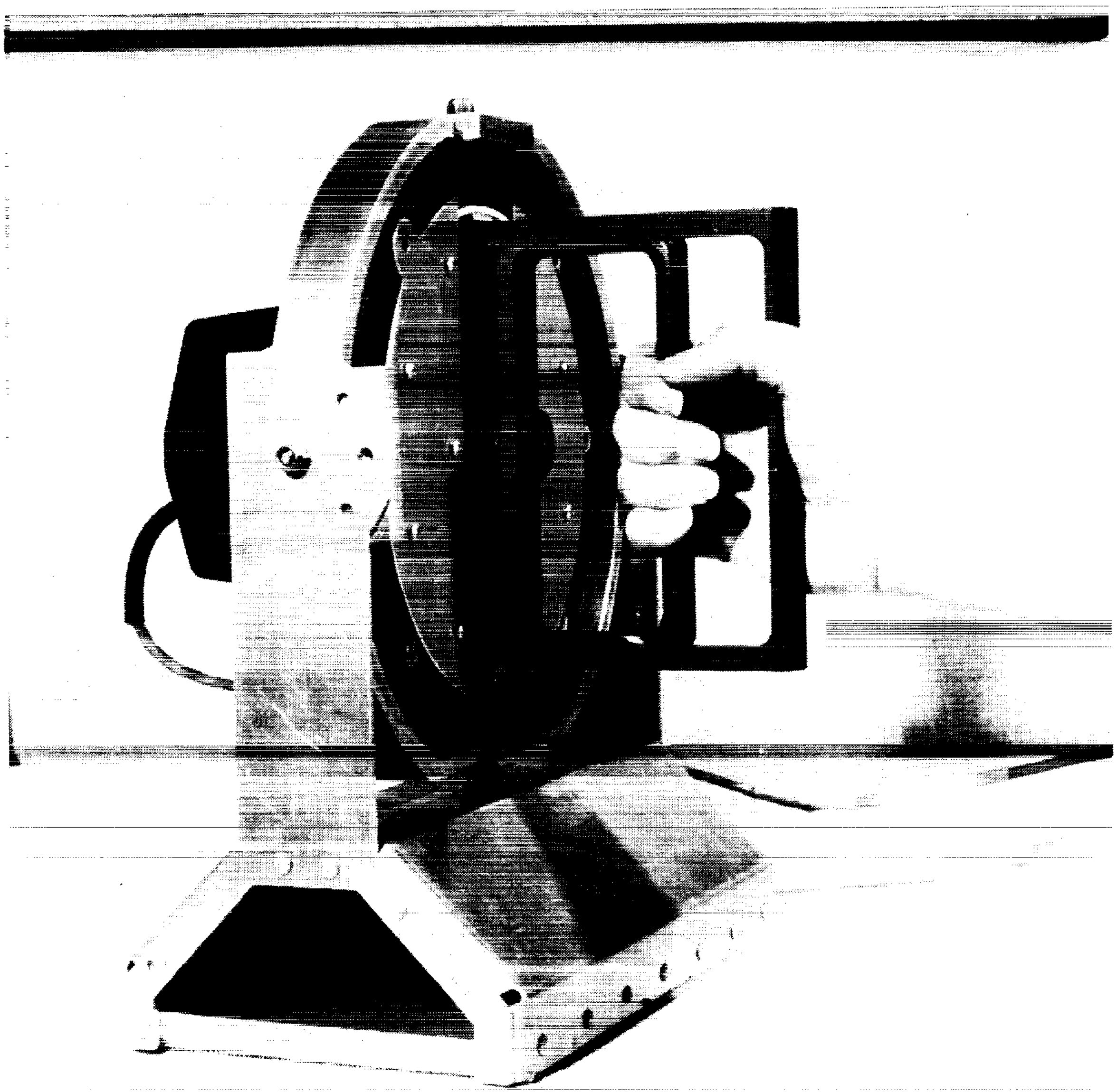

Figure 1. Grip Dynamometer

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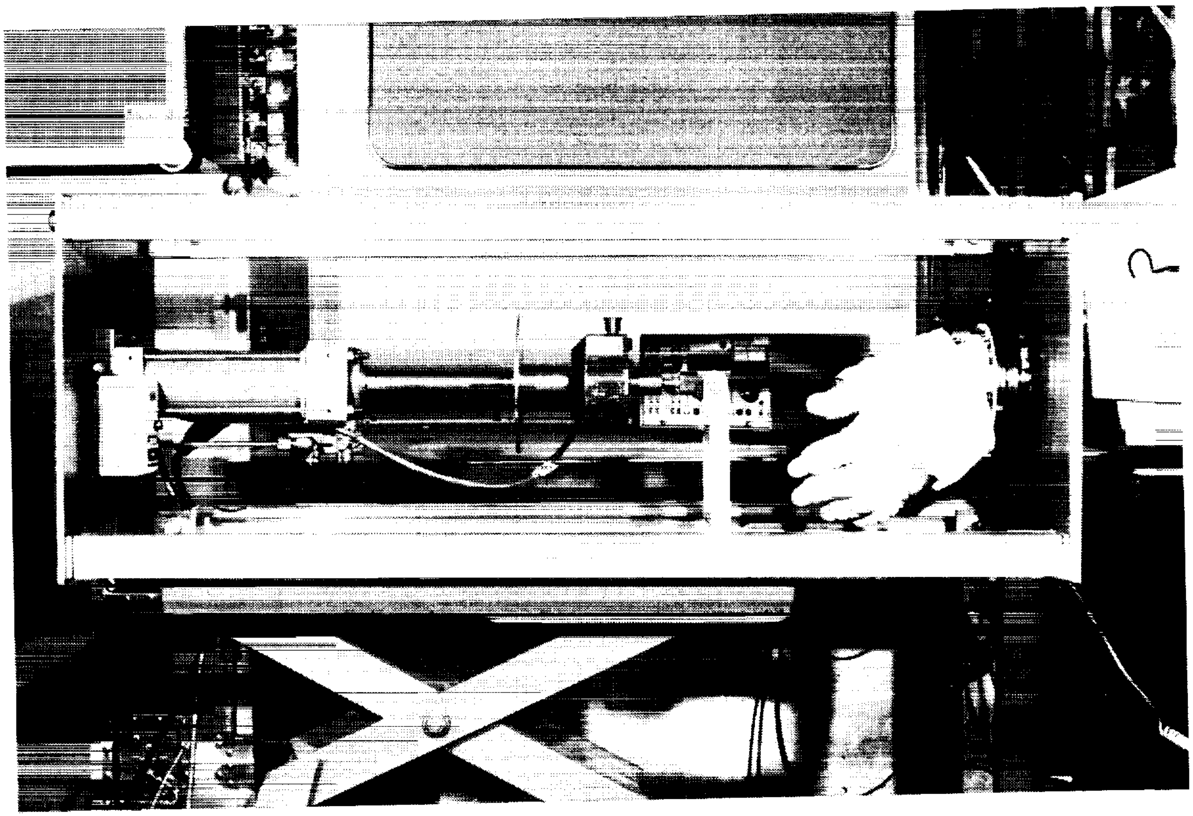

Figure 2. Hand Grasp Breakaway Test Equipment

from the subject's hand. An unpressurized 4000 series EVA glove was attached to the enclosed structure via a spring-loaded attachment. The apparatus was mounted on a hydraulic jack for height adjustment. The signals from the load cell and the grip dynamometer were collected at the rate of 100 Hz on line via an Ariel data acquisition system (Ariel Performance Analysis System, LaJolla, CA). Prior to the actual experiment, both the load cell and the grip dynamometer were calibrated.

EXPERIMENTAL DESIGN

A repeated measures design was used in this study. The experiment tested the difference between (1) different subject populations, (2) males and females, and (3) the right and left hands.

Since there were unequal numbers of males and females in the general and the astronaut groups, the design treated the data as belonging to five groups. These groups were as follows: (1) general-male group, (2) general-female group, (3) astronaut-male group, (4) astronaut-female group, and (5) SML III test subject group. Hence, the independent variables or the test conditions were (1) the subject group with five levels and (2) hand (right vs left) with two levels.

The dependent measures included the maximum hand grasp breakaway strength and the maximum hand grip strength. In addition to the strength measurements, the following anthropometric data were collected: (1) hand length, (2) palm length, (3) forearm length, (4) upper arm length, (5) wrist circumference, (6) forearm circumference, (7) upper arm circumference, (8) height, and (9) weight. The procedure for measuring hand anthropometry was obtained from the Anthropometric source book (Webb Associates, 1978).

EXPERIMENTAL PROCEDURE

Each subject signed a consent form prior to the test. The subject was given brief instructions on how to perform the experiment. During the grip strength test, the subject adjusted the chair height so that his or her elbow was at a right-angled position. Then, the test conductor manually adjusted the handle position so that the subject could hold the handle comfortably. After a few practice trials, the subject was asked to exert maximum grip strength and maintain it for about three seconds. A rest period of about 2 minutes was given between trials to minimize fatigue effect. A total of three trials were conducted for each hand.

After the grip strength testing, several anthropometric measurements were taken from the subject. Next, the subject was taken to the hand grasp breakaway strength test site. The subject tried different glove sizes and chose the one that fit his or her hand best. Then the subject adjusted the chair to maintain the elbow at a right angle. The glove was fitted to the structure and the subject inserted either the right or left hand into the glove through a circular opening in the structure. The handrail position was adjusted so that the subject could hold the handrail firmly. During testing, the subject was instructed to grasp the handrail tightly and resist the effort of the pneumatic cylinder while it was pulling the handrail away from the subject's hand. Three trails were administered for each hand and a rest period of 2-3 minutes was given between trials. The strength tests and the anthropometric data collection took about 45 minutes for each subject.

DATA TREATMENT

The on-line data collected from each subject were analyzed individually for each trial and for each combination of the test conditions. The grip strength was calculated by averaging the data within the time window during which the subject maintained a constant strength. The grasp strength was obtained by determining the force at which the subject let go of the handle. Once the maximum strength values were obtained for each subject and for each trial, the strength data, along with the anthropometric data and the data containing subject's classification (sample population, sex, hand, etc.), were exported to the mainframe (VAX) computer for statistical analyses.

STATISTICAL ANALYSES

In order to obtain meaningful information from the data, three different analyses were conducted on the dependent variables. First, the overall peak strength that occurred within each group and for each hand was determined. This was done by identifying an individual's peak strength and grasp strength for right and left hands separately. A peak strength was defined as the maximum strength value among the three trials of strength data. Using the individual peak values, the overall peak grip strength and grasp strength with right and left hands were selected for each group.

In order to compare whether there were any differences among the SML III subjects, astronauts, and the subjects from the general population as a group, both multivariate analysis of variance (MANOVA) and univariate analysis of variance were used. First, MANOVA was performed to determine whether the hand strength (grip and grasp strengths combined) **as a whole** was significantly different among the groups and between hands. The interaction between these two test conditions was also examined. Then ANOVA was conducted to determine how different **each strength measure** was individually, within the groups and between hands. Finally, multiple comparisons tests were performed to identify the amount of difference among the five groups and between right and left hands.

Finally, stepwise regression analysis with forward selection procedure was used to predict the grasp breakaway strength from the grip strength, sex, hand, population, and the ten anthropometric variables.

RESULTS

DESCRIPTIVE STATISTICS

Table 3 contains the overall peak grip strengths for the right and left hands within different subject groups. The table shows that the overall peak grip strength (684 N) occurred within the SML III test group. The individual peak grip strength within the astronaut group (669 N) was slightly greater when compared to the general subject group (657 N).

Within each male-subject group, the peak grip strength with the right hand was greater than with the left hand. In contrast, the female-subject groups exhibited somewhat similar peak strengths with their right and left hands. In general, the male-astronaut group and the male-general group exhibited similar peak grip strengths (right hand: 669 N vs. 657 N; left hand: 604 N vs. 608 N). The peak grip strength of the female-astronaut group (right: 287 N; left: 268 N) was less than that of the female-general group (right: 407 N; left: 409 N).

Table 3. Descriptive Statistics on Grip Strength

Subject Group	N	Overall Peak Grip Strength	
		Right Hand (N)	Left Hand (N)
Normal-Male	5	657	608
Normal-Female	19	407	409
Astronaut-Male	15	669	604
Astronaut-Female	3	287	268
SML III	5	684	643

Table 4 contains the overall peak grasp strengths for the right and left hands within different subject groups. The table shows that the overall peak grasp strength (1218 N) also occurred within the SML III test group. The overall peak grasp strength of the astronaut group (1103 N) was slightly greater than that of the general subject group (1096 N).

Within each group, the peak grasp strength with the right hand was greater than with the left hand. The male-astronaut group and the male-general group exhibited similar peak grip strengths (right hand: 1096 N vs. 1103 N; left hand: 979 N vs. 1021 N). The peak grasp strength of the female-astronaut group (right: 704 N; left: 695 N) was less than that of the female-general group (right: 794 N; left: 717 N). Finally, a comparison of Tables 3 and 4 shows that the subjects as a group, had peak grasp strengths twice as much as the peak grip strengths.

Table 4. Descriptive Statistics on Grasp Strength

Subject Group	N	Overall Peak Grasp Strength Right Hand (N)	Overall Peak Grasp Strength Left Hand (N)
Normal-Male	5	1096	979
Normal-Female	19	794	717
Astronaut-Male	15	1103	1021
Astronaut-Female	3	704	695
SML III	5	1218	1042

MANOVA

The MANOVA results showed that there were significant differences in the overall mean hand strength (grip and grasp combined) between right and left hands ($F\{2,286\} = 4.8$; $p < 0.009$). The differences among the five different subject populations were marginally significant ($F\{8,572\} = 8.2$; $p < 0.064$). The interaction between hand and the subject groups was also significant ($F\{8,572\} = 2.11$; $p < 0.0328$). This significant interaction suggested that the strength characteristics of right and left hands were not the same across the groups.

ANOVA

Subsequent ANOVA results indicated that there was a significant difference in mean grip strength ($F\{4,287\} = 217.07$; $p < 0.0001$) and mean grasp strength ($F\{1,287\} = 211.75$; $p < 0.0001$) among the groups.

Multiple comparisons tests showed that the SML III test subject group's mean grip strength (577 N) was significantly greater than the remaining groups. There was no significant difference in mean grip strength between the general-male and astronaut-male groups (496 N vs. 484 N). The mean grip strength between the general-female group (258 N) and the astronaut-female group (249 N) was not statistically significant. The two female subject groups had a significantly lower strength than the three male subject groups.

Multiple comparisons tests showed that the differences in mean grasp strength among the SML III, general-male, and the astronaut-male groups were not significant. The SML III group's mean grasp strength was 940 N, the general-male group's strength was 878 N, and the astronaut-male group's strength was 872 N. The two female groups had a significantly lower grasp strength than the three male groups; however, the general-female group's strength (480 N) was not statistically different from the astronaut-female group's strength (438 N).

There was a significant difference in the mean grip strength between right and left hands ($F\{1,287\} = 6.01$; $p < 0.01$). The multiple comparisons tests showed that the overall mean grip strength for the right hand was 403 N and for the left hand was 383 N. There was also a significant difference in the mean grasp strength between right and left hands ($F\{1,288\} = 21.90$; $p < 0.0021$). The mean grasp strength for the right hand was 736 N and for the left hand was 669 N.

STEPWISE REGRESSION ANALYSIS

It was evident from the previous sections that the grasp breakaway strength was affected by the variables sex, hand, and the group to which the subjects belonged. In addition to these variables, it was expected that the hand anthropometric variables, as well as the

Table 5. Stepwise Regression Analysis Results

$$\text{Grasp Strength (N)} = -83.95 + 0.81\,(\text{Grip Str.}) - 31.40\,(\text{Group}) - 32.14\,(\text{Hand}) + 2.42\,(\text{Weight}) + 61.44\,(\text{Hlen}) - 65.71\,(\text{Plen}) + 24.40\,(\text{Flen}) - 14.22\,(\text{Ulen}) - 101.42\,(\text{Sex})$$

Regression Coefficient= +0.93

Error = +/- 88 N

where:				
	Grip str.	is	Grip strength	in N
	Group	is	1 for general, 2 for astronaut, and 3 for SML III subjects	
	Hand	is	1 for right and 2 for left	
	Weight	is	Body weight	in Kg
	Hlen	is	Hand length	in cm
	Plen	is	Palm length	in cm
	Flen	is	Forearm length	in cm
	Ulen	is	Upper arm length	in cm
	Sex	is	1 for male and 2 for female	

other variables such as age, height, and weight, might also affect the grasp breakaway strength. A stepwise regression analysis was used to determine a multiple variables-based linear regression model to predict the grasp breakaway strength. The analysis began with grip strength as the main predictor, which accounted for 86 percent of the variations in the grasp strength. Other variables were included in the model one by one in the subsequent steps. The final model predictor, which accounted for 86 percent of the variations in the grasp strength. Other variables were included in the model one by one in the subsequent steps. The final model accounted for a maximum of 93 percent variability in the grasp breakaway strength data. However, the mean error in prediction with the model was (±) 88 N. Table 5 shows the results from stepwise regression analysis.

DISCUSSION

The objectives of this study were to (1) document the grip and grasp strength capabilities of the astronauts and the five SML III test subjects, (2) verify whether the subjects selected within the SML III group are stronger than the astronauts and the subjects from the general group, (3) determine whether the mean strength capabilities of the astronaut population and the SML III group are similar to a sample of subjects from the general population, and (4) model the variations in the hand grasp breakaway strength by hand grip and hand anthropometry.

First, this study documented the individual maximum grip and grasp strength capabilities of the astronauts and the five SML III test subjects.

The overall peak grip strengths within the astronaut group and the general population were less than the SML III test subject group. In terms of group mean strength, the SML III test subject group's mean grip strength was significantly greater than the other groups'. There were no significant differences in the mean grasp strength among the three male groups. Overall, the results suggest that the SML III test subjects were stronger than the other subjects.

Regardless of which group they belonged to, most subjects could grasp twice as much as their grip strengths. This result was in agreement with other studies (Fujii, 1989; Roesch, 1987). Earlier studies on muscle and joint behavior have also cited that eccentric (grasp) strength is comparatively greater than the concentric (grip) strength (Komi, 1973; 1979; Bigland and Lippold, 1952). As a group, the SML III test subjects had a greater mean grip strength than the other two male groups. In contrast to this difference in grip strength, the three male groups exhibited similar mean grasp strengths. The two female groups had similar mean grip and grasp strengths; however, their grasp and grip strength capabilities were about 50% of the males' strengths. The difference in grip strength between male and female groups was roughly the same as cited in other studies (Fujii, 1989; Rajulu et al., 1988).

The results showed that the right hand was slightly stronger than the left hand. The difference in the mean grip strength between right and left hands was 19 N and the difference in the grasp strength between right and left hands was 66 N. It should be pointed out that the subjects were all right handed with the exception of three subjects. Hence, it was not surprising to see that the right hand was stronger than the left hand. However, in contrast to the males, the female subjects exhibited similar strengths with their left and right hands.

Finally, stepwise regression analysis showed that grip strength alone accounted for about 87 percent variability in the grasp strength. By adding additional variables such as weight, sex, upper arm length, hand (right vs. left), hand length, forearm length, palm length, height, and the group, the regression model accounted for about 93 percent variability in the grasp strength. However, the overall error in predicting the grasp strength was +/- 88 N (20 lb). Thus, prediction of grasp strength with the grip strength and the anthropometric variables was less accurate than expected. The reason for such a large error in prediction is that the muscular mechanism responsible for eccentric contraction is very different from the one that facilitates concentric contraction (Komi, 1979). Furthermore, the variability in grip strength among subjects was quite high when compared to the variability in grasp strength. This was supported by the statistical results which showed significant differences in the mean grip strength among male subject groups but no significant differences in the mean grasp strength.

CONCLUSION

This study collected the maximum grip and grasp strengths of 18 astronauts and the 5 SML III test subjects. These data were collected primarily to determine the maximum load that the astronauts may impart during an EVA. The grasp strength data from this study and the results from the SML III test will be used to obtain the maximum loads for each astronaut.

This study found that one of the SML III test subjects grasped more (1218 N) than the general subjects (1096 N) and the astronauts (1103 N). The individual maximum grip strength was also attained by one of the SML III test subjects (684 N). The SML III test subject group also had a greater mean grip strength than the other groups and a similar mean grasp strength as the other male groups. Based on these results, it is concluded that the SML III subjects are stronger than the astronauts as well as the subjects from the general population. Hence, it is likely that the SML III test data are sufficient to determine the maximum possible loads on the suit.

As a group, subjects from the SML III were able to grip more than the astronauts and the subjects from the general group. However, there were no differences in mean grasp strength among the three male groups. In general, the female astronauts and the male astronauts were equally strong in comparison to the subjects selected from the general population. As expected, females were less strong (about 50%) than the males. In general, the right hand was stronger than the left hand.

The multiple linear regression model based on grip strength and hand anthropometry was found to be less accurate than expected. Hence, it is not possible to predict the grasp strength without encountering significant errors. In brief, it is necessary to collect the hand grasp breakaway strength from the astronauts in order to estimate the maximum loading on the suit.

FUTURE RECOMMENDATIONS

In this study, strength measurements were made with the subjects using one hand at a time. Most EVA tasks will require both hands to be used. It is not certain whether a subject can exert more strength with two hands as compared to the strength value that can be obtained by adding the strengths of the right and left hand. If the actual strength happens to be greater than the calculated sum, it is then necessary to obtain the strength data with two hands together. It is also recommended to investigate whether grasp strength can be enhanced by using different types of handles. Enhancement of the grasp strength might help the astronauts to perform their tasks with increased efficiency. Finally, as an addendum to the results from this study, another study might be considered to determine whether the grasp strength is affected by wearing pressurized gloves.

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13. ABSTRACT *(Maximum 200 words)*
Astronauts have the task of retrieving and deploying satellites and handling massive objects in and around the payload bay. Concerns were raised that manual handling of such massive objects might induce loads to the shuttle suits exceeding the design-certified loads. The Crew and Thermal Division of NASA JSC simulated the satellite handling tasks (Satellite Manload Tests I & III) and determined the maximum possible load that a suited member could impart onto the suit. In addition, the tests revealed that the load to the suit by an astronaut could be calculated from the astronaut's maximum hand grasp breakaway strength. Thus, this study was conducted to document the hand grasp breakaway strengths of the astronauts who were scheduled to perform EVA during the upcoming missions. In addition, this study verified whether the SML III test results were sufficient for documenting the maximum possible load. An attempt was made to predict grasp strength from grip strength and hand anthropometry. Based on the results from this study, the SML III test results were deemed sufficient to document the maximum possible load on the suit. Finally, prediction of grasp strength from grip strength was not as accurate as expected. Hence, it was recommended that grasp strength be collected from the astronauts in order to obtain accurate load estimation.

14. SUBJECT TERMS
Grip strength, grasp strength, regression model, anthropometry

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