41st International Conference on Environmental Systems
17 - 21 July 2011, Portland, Oregon

AIAA 2011-5085

Effects of EVA Glove on Hand Performance

Silvia Appendino[1], Elisa P. Ambrosio[2], Fai Chen Chen[3], Alain Favetto[4], Diego Manfredi[5], Mehdi Mousavi[6], and Francesco Pescarmona[7].
Italian Institute of Technology, Center for Space Human Robotics, Corso Trento 21, 10129, Torino, Italy

The human hand is a very particular limb: it has a wide range of degrees of freedom, permitting to achieve a great variety of movements, and is also one of the most sensorized parts of the human body. These characteristics make it the most important tool for astronauts to perform extravehicular activity (EVA). However, mandatory EVA equipment strongly reduces hand performances, in particular as regards dexterity, tactile perception, mobility and fatigue. Several studies have been conducted to determine the influence of the EVA glove on manual capabilities, both in the past and more recently. This study presents experimental data regarding the performance decay which occurs in forces, fatigue and capability to execute tasks when wearing a non pressurized EVA glove, in comparison with bare-handed potential. Moreover, mechanical resistance of the glove has been measured and imposed pressure maps are presented. Results yield a deeper knowledge on how EVA gloves hinder human hand performance and how this is related to their stiffness.

Nomenclature

EVA	=	Extravehicular Activity
EMU	=	Extravehicular Mobility Unit
TMG	=	Thermal Micrometeoroid Garment
EMG	=	Electromyography

I. Introduction

EXTRA vehicular activity (EVA) has been part of space activities since the 1960s. In the forthcoming years NASA plans to increase significantly the number of hours dedicated to EVA operation during space missions[1]. It is therefore important that the astronaut's equipment allows doing this as efficiently as possible. The most important tool for astronauts is their own hand: it has a wide range of degrees of freedom, permitting to achieve a great variety of movements, and it is also one of the most sensorized parts of the human body (its projection in the primary motor cortex in the brain is among the largest ones of the body[2]). Human hand dexterity and perception are the main factors in man's superiority over artificial devices in adaptive and complex tasks that cannot be completely defined in advance. During EVA, the hand is not only a multi-purpose tool but also the primary means of locomotion, restraint and tool handling.

The current EMU (Extravehicular Mobility Unit) suit is composed by a complex and highly technological multilayer system inflated by air in order to protect the astronauts from the extreme environment in which they

[1] Post-doc researcher, Italian Institute of Technology, Center for Space Human Robotics, Corso Trento 21, 10129, Torino, Italy
[2] Post-doc researcher, Center for Space Human Robotics, Corso Trento 21, 10129, Torino, Italy.
[3] PhD student, Dipartimento di Meccanica, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Torino, Italy
[4] PhD student, Dipartimento di Automatica e Informatica, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Torino, Italy
[5] Post-doc researcher, Center for Space Human Robotics, Corso Trento 21, 10129, Torino, Italy.
[6] PhD student, Dipartimento di Meccanica, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Torino, Italy
[7] Post-doc researcher, Center for Space Human Robotics, Corso Trento 21, 10129, Torino, Italy.

operate. All these factors, although necessary, impose strong limitations to the mobility and dexterity of astronauts during missions, increasing the stiffness of each joint and requiring a greater than normal force to perform tasks.

Gloves are probably the most critical part of the suit because almost all operations involve the use of the hands. The problem related to the stiffness of the suit is thus amplified in this case, increasing sharply the fatigue of the hand and forcibly limiting the overall duration of EVAs.

Several studies have been conducted to determine the influence of the EVA glove on manual capabilities, both in the past[3,4] and more recently[5,6].

Six basic hand characteristics have been identified in literature[3]: range of motion, strength, tactility, dexterity, fatigue and comfort. These aspects have been studied in several papers[3-6] following different methods.

In this paper the glove effects related to hand forces and fatigue have been studied. Moreover, the mechanical resistance of the glove has been measured and analyzed, both in terms of induced pressure localization and of its numerical value. It has to be pointed out that all tests have been hitherto performed without pressurizing the glove, thus the results present just a portion of EVA glove effects: previous studies[4,7-9] demonstrate that pressurization makes performance even worse. The methodology used to perform tests is presented: used equipment and experimental setups are described, as well as the subject population participating in the study. Experimental results are then shown and discussed.

II. Test Methodology

In order to evaluate the influence of the EVA glove on the performances of the human hand, two different tests have been designed to evaluate separately the effects of the glove on fatigue and the resisting forces that the glove opposes to hand and finger movements. The details of those tests and the materials used are described in the following.

A. EVA Glove

The EVA glove under test (Fig. 1) is a left Russian Orlan-DM glove[10], which is the only EVA glove currently available to us. This limited the execution of the tests to the left hand and to a single type of glove, but we are planning to extend the measurements to the right hand and to other kinds of gloves as they become available to us. The use of a particular EVA glove (Orlan – DM) in this series of tests does not limit the application of the related methodology. The EVA glove under test is composed of three elements: an inner rubber glove (a), the properly named EVA glove (b) and the outer Thermal Micrometeoroid Garment (TMG) (c). The tasks for which the use of the glove was foreseen have been performed wearing all components of the glove, comprising the TMG.

Figure 1. Orlan-DM glove used for testing. *Inner rubber glove (a), EVA glove (b), and outer TMG (c).*

B. Subjects

16 test subjects participated in this study. The test subject pool includes 7 females and 9 males, ranging in age from 25 to 36. Among the 16 test subjects, 2 are left-handed and 14 are right-handed. All subjects were volunteers and had never worn an EVA glove before. Subjects were selected with one criterion depending on their hand size: their left hand had to fit inside the glove. In particular, the volunteer’s fingertips had to touch the glove fingertips without feeling uncomfortable and, at the same time, his finger webbings had to correspond to the bases of the glove fingers. Moreover, each subject tried to perform the test tasks before the actual start of the test, giving an oral feedback on sensation: if they felt unable to effectively achieve the requested movements, they could not participate in the study.

C. The test tasks

Literature identifies and classifies several types of hand grips, mainly divided into power and precision grips, according to exerted forces. Power grips involve muscles on the forearm whereas precision grips mostly use hand and finger muscles. Precision grips are typically performed by two or three fingers and are called *pinches*. In this study, four different tasks have been chosen, as can be seen in Fig. 2, in order to evaluate different kinds of grips, using the whole hand or only a few fingers. The choice of tasks involving a different number of fingers stems from a study[11] claiming that 2 fingers can perform 40% of the possible hand tasks, 3 fingers can accomplish 90% and 4 can complete 99%. Therefore, it is interesting to see the influence of the glove while varying the number of fingers involved in each task. Grip nomenclature is not universal, thus the chosen grips have been named as follows:

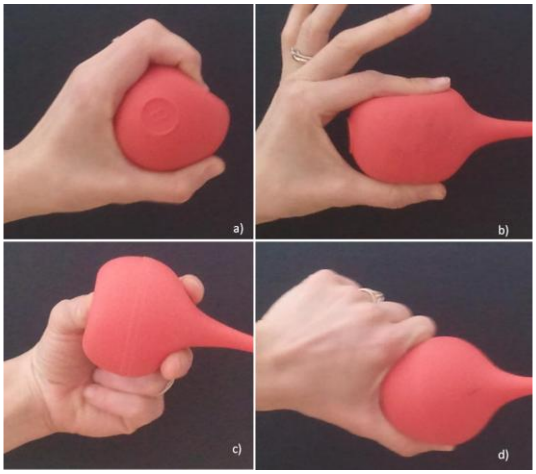

Figure 2. The four tasks chosen for the tests. *a) power grip, b) two finger pinch, c) three finger pinch, d) lateral pinch.*

1. Power grip (Fig. 2a): power grasp performed using all five fingers, with the thumb opposing to the other fingers
2. Two finger pinch (Fig. 2b): precision pinch performed using only the thumb and index
3. Three finger pinch (Fig. 2c): precision pinch performed with the thumb opposing to the index and middle finger
4. Lateral pinch (Fig. 2d): intermediate pinch performed with the thumb in opposition to the fist side.

Those four tasks have been applied to both fatigue and opposing force tests.

D. Experimental setup and test sequence for performance measurement

A simple pneumatic setup, depicted in Fig. 3, has been realized for performance measurement. A bulb syringe is connected to a constant volume and to a manometer. As the subjects were executing the required task, the bulb syringe was pressed increasing the air pressure inside the pneumatic circuit. This pressure was measured by means of the manometer. All the subjects were shown the pictures of the grips they should perform (Fig. 2) and the same instructions, which are listed hereafter:

1. Hold the bulb syringe with your left hand as shown in the picture
2. Apply the highest force you are able
3. Maintain this configuration for about 1s
4. Return to relax position
5. Repeat until you feel too tired to continue

These instructions were given for each test, for a total of 8 tests per subject (4 kinds of grips performed both with and without glove). Subjects performed at most one test (a complete series of repetitions of a single task, either with or without glove) in the morning and one in the afternoon in order to guarantee that each task was started with no initial fatigue.

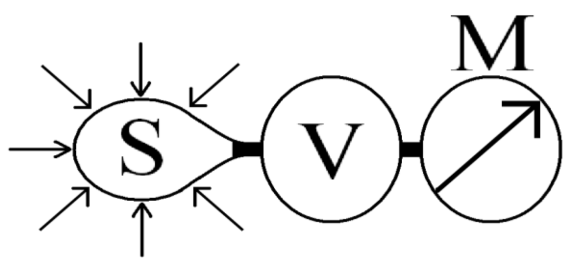

Figure 3. Pneumatic circuit scheme

Since the instructions did not impose a fixed number of hand grip cycles, subjects would stop after a variable number of repetitions. In most cases, beside fatigue, also motivation could influence the amount of performed cycles. One subject pointed out that she was much more motivated when wearing the glove, because she felt it was an uncommon and somewhat exciting situation. For each grasp cycle (where cycle is intended as performance of points 2-4 of the instruction list), the maximum pressure was recorded. Force is directly correlated to the maximum pressure value whereas fatigue can be associated both to the decrease of maximum pressure value in time, and to the total number of cycles performed for each test. The latter, however, is probably less significant, since fatigue is a subjective physiological and mental effect that can be strongly influenced by factors like motivation, commitment, and well being at the time of the test[10].

E. Experimental setup and test sequence for glove resistance measurement

The opposing forces that the glove imposes on the hand have been measured by means of a commercial pressure sensor system, GRIP® System[12] by Tekscan Inc. The system consists of a tree of sensor arrays geometrically configured so to fit directly on a hand (or a glove) and measure contact forces in significant points. Each hand sensor has 18 sensing regions, consisting of an array of tactile pressure sensors. The sensor technology is based on two thin, flexible polyester sheets which have electrically conductive electrodes deposited in appropriate patterns (rows and columns, respectively on the two sheets); the intersection between rows and columns realizes a sensing area. The system also comprises a software which permits real-time visualization of the pressure maps and data post-processing.

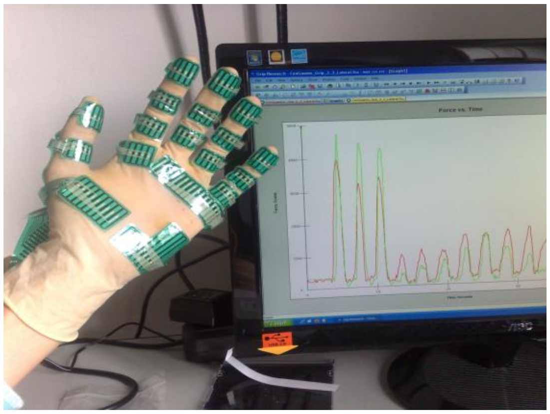
Figure 4. Sensorized garment (and acquired curves on the background).

The sensors were fixed on a glove, in order to keep them in place and guarantee the repeatability of the tests. A latex glove has been chosen due to its thinness, which does not add significant resistance to that coming from the EVA glove. Once fixed on the glove, sensors have been calibrated and residual stress on sensors was brought to zero via software, so to minimize measurement errors. Figure 4 shows the sensorized latex glove and the post-processed data related to a test.

The test procedure consisted in repeating the four tasks described in paragraph II.C (power grip, two finger grip, three finger grip and lateral grip) in free space, without holding the bulb syringe, in order to measure only the mechanical stiffness of the glove and no external forces. The movements have been repeated in two different conditions: wearing only the sensorized glove on the bare hand and with the complete EVA glove. In each condition, the following movement protocol was attained to: hand at rest, three cycles of power grip, three cycles of two finger pinch, three cycles of three finger pinch, three cycles of lateral pinch, hand at rest. A metronome gave timing for the execution of movements, in order to make it easier to overlay the curves and see how they would differ. The movement protocol was repeated three times in order to evaluate repeatability, yielding a total of 9 repetitions per task.

III. Results and Discussion

A. Effects of EVA glove on performance

The results of the tests show that the effects of the EVA glove on performance are strongly related to the executed task. As regards the power grip and the lateral pinch, wearing an EVA glove significantly reduces strength in almost all subjects, and also increases considerably fatigue effects, as can be seen both by the total number of executed cycles as by the performance decay in time. On the other hand, two finger and three finger pinches are performed with hardly any difference, as if the glove had almost no effect. Results presented no significant difference between male and female subjects: men have obviously a higher maximum strength on average, but data for each subject were processed as a percentage of their own maximum value, thus cancelling the effects due to each subject's physical presence.

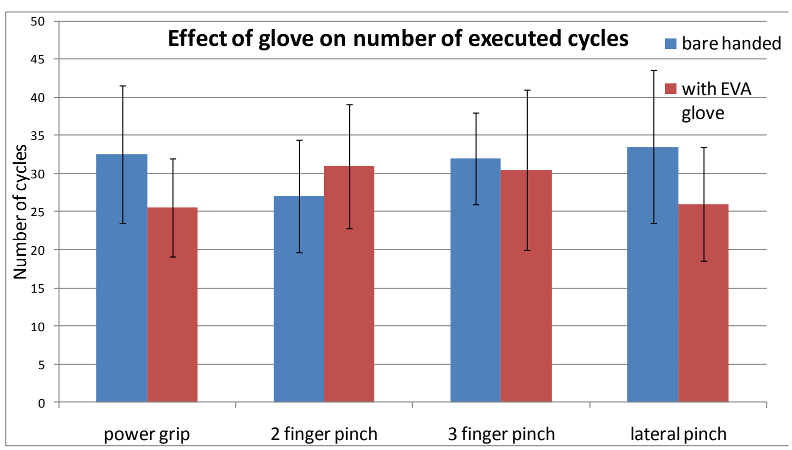

Figure 5. Effect of glove on number of executed cycles for each task

Figure 5 shows the effect of the glove on the number of executed cycles for each task. The average number of executed cycles is shown, with the associated standard deviation, for each task with and without glove. It is immediate to notice that the greatest influence is on the power grip and on the lateral pinch. In the case of the two finger pinch, the result is opposite to expectations: this may be due to factors such as motivation, added to the fact that glove doesn't particularly hamper such task. Also as regards the three finger pinch, EVA glove effects on the number of executed cycles is not very significant.

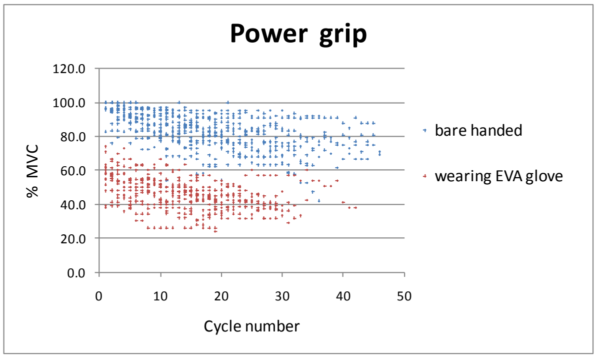

Figure 6. Effects of wearing EVA glove on power grip performance

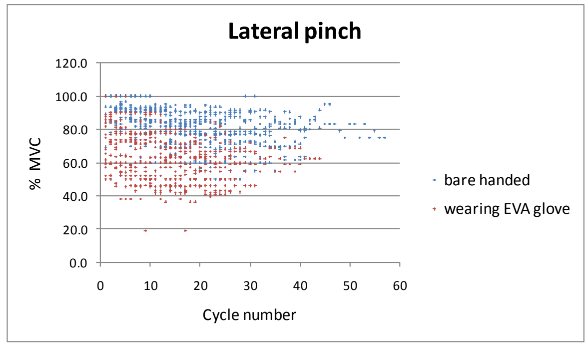

Figure 7. Effects of wearing EVA glove on lateral pinch performance

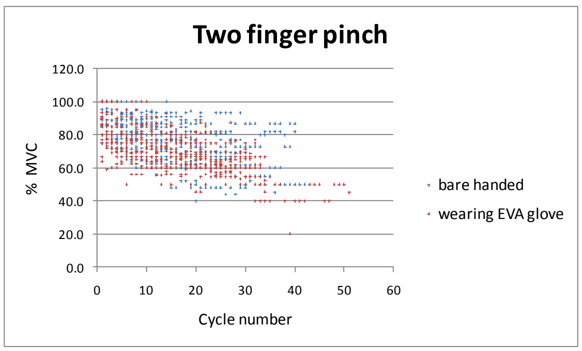

Figure 8. Effects of wearing EVA glove on 2 finger pinch performance

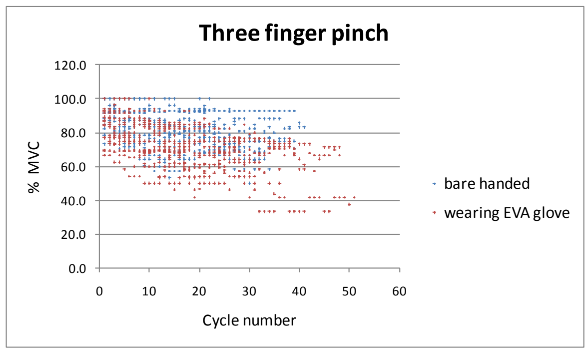

Figure 9. Effects of wearing EVA glove on 3 finger pinch performance

The same trend can be found when analyzing glove effects on strength. In the case of the power grip and of the lateral pinch, strength decreases significantly when wearing the EVA glove. Figures 6-9 show the difference between task performance with and without glove. All values are expressed as percentages of the maximum force of each subject (maximum voluntary contraction, %MVC) for that task, so that the data of all subjects can be presented on the same graph. Blue points are related to tests performed bare-handed, whereas red points are performed wearing the EVA glove.

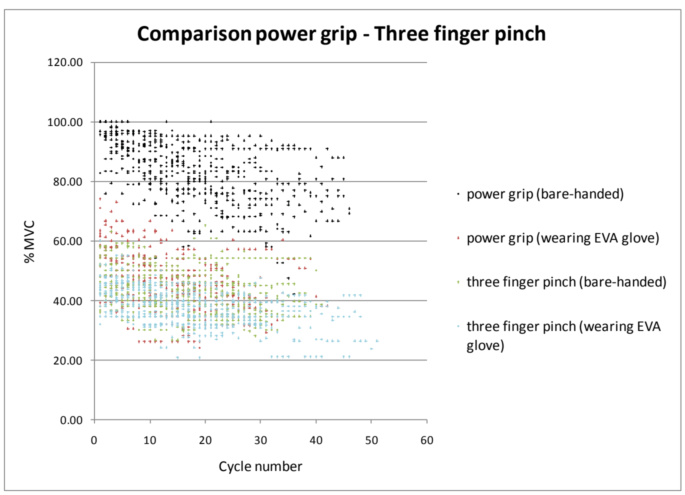

Figure 10. Comparison between power grip and 3 finger pinch with and without EVA glove.

As regards power grip (fig. 6), two distinctly separate point clouds are visible: thus in all cases performances wearing the EVA glove were significantly lower than bare handed ones. Strength diminishes by 40% to 60% in all subjects, and also in this case the reduction of performed cycles is clear. The effects on lateral pinch (Fig.7) are slightly different: the two clouds have different mean values, but they are partially overlapping. Four subjects (3 females and 1 male) have actually performed similar lateral pinches with and without glove, whereas the remaining 12 subjects have clearly distinct curves.

On the other hand, as regards two and three finger pinches, wearing the EVA glove seems to produce little or no effect at all (Fig. 8 and 9) on performances. Clouds of points are almost indistinguishable, and there is no prevalence of one color on the other in certain areas. Moreover, the total number of performed cycles is about the same, as fig. 5 already demonstrated.

Although these results may seem unexpected, they are in line with previous research. Bishu and Klute state[4] that grip strength is reduced by 50% when wearing unpressurized EVA glove, whereas pinch strength is reduced by only 10%. Also the studies performed by O'Hara[3] assess an average strength reduction of 60% for grip force and a on significant reduction for pinch force due to unpressurized EVA glove. This brings to the consideration that the real problem may be in the bulk of the glove, more than in its stiffness, also considering the fact that tests were performed in unpressurized conditions (pressurization further increases the stiffness[4,7-9]). Actually, the results – for the tasks selected for this study, thus grasping the bulb syringe with its particular shape and dimension - show that wearing the EVA glove performances with the whole hand are almost the same as using only three fingers, as if the ring finger and the little finger were too far, too weak or too hampered to help.

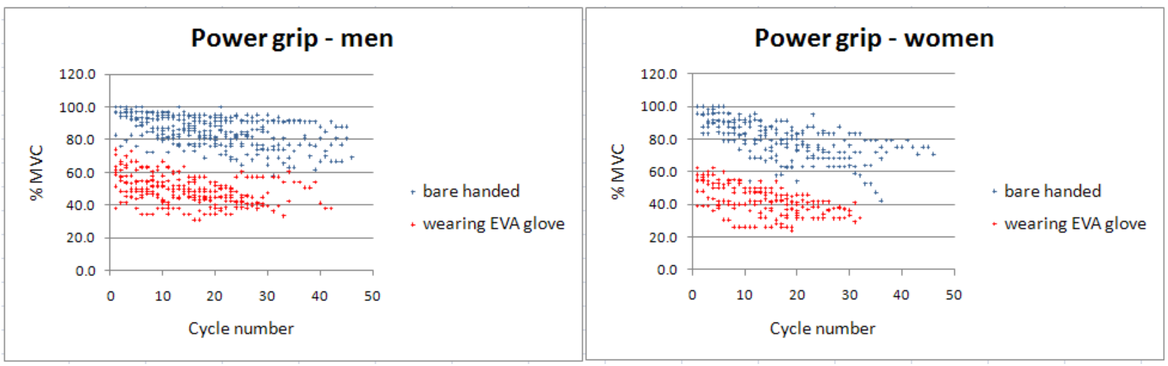

Figure 11. Effect of EVA glove on the power grip of men (a) and women (b)

Figure 10 depicts the difference between power grip with and without EVA glove compared to the three finger pinch with and without glove, considering the maximum overall performance of the test subject as 100%MVC: it is interesting to notice that power grip performance wearing the EVA glove overlaps the three finger pinch, both with and without the glove. This may be due to the glove itself or to the shape and dimension of the bulb syringe used for the tests: it would be interesting to check if similar results would arise with different geometries of the grasped object.

Analyzing data separately for men and women, although the differences are not wide, brought to a consideration: the effect of the glove is not proportional to the subject's strength, but is somehow an absolute value, thus it has a larger relative influence on weaker subjects (e.g. women). Figure 11 shows how the effects of EVA glove on power grip operate on men (Fig. 11a) and on women (Fig. 11b): the effect is very similar, but in the case of women the two point clouds are more distant. Actually almost no female subject achieved more than 60% MVC when wearing the glove, whereas men achieved up to 74%. Also minimum values for men are higher (around 32%) than for women (around 24%). For this reason, the pressure differentials have been considered worthy of evaluation and figure 12 depicts, for men and women, the pressure difference between bare-handed and gloved value of each cycle of the power grip test. As can be seen, the points are equally distributed between men and women and therefore the force reduction due to the glove may be considered independent from the subject's strength.

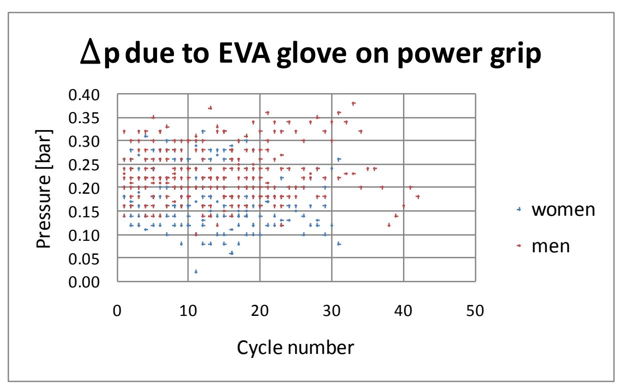

Figure 12. Difference in maximum pressure value between bare-handed and gloved condition for men (red points) and women (blue points).

B. Measurement of EVA glove opposing forces

The tasks performed during the first research phase have been repeated wearing a sensorized glove (as described in paragraph II.E) but in air, i.e. without grasping any object. If any force is recorded between the hand and the glove, then it is due to the glove resistance against the hand. Tasks have been performed wearing only the sensorized glove, and then wearing the complete EVA glove on top of it. Sensor calibration has been effected in order to zero the pressure conditions in hand rest position. Each task has been performed 9 times and the presented results are the average of those acquisitions. Figure 13 shows the total force which the EVA glove exerts on the hand for each task, with the associated standard deviation.

It is clear how this is very significant for power grip, reaching peak values of 38N, whereas it is lower for the pinches. However, it is important to point out that the depicted value is the integral of all pressures on the whole hand surface: thus if a movement involves only a small part of the hand, even small total forces may be the result of locally significant pressures. Moreover, not all hand areas are sensorized, as can be seen in Fig. 4. In particular as regards lateral pinch, the side of the thumb and of the index are not sensorized, although they are the most involved areas. Therefore mapping of pressures, as well as their values, is important.

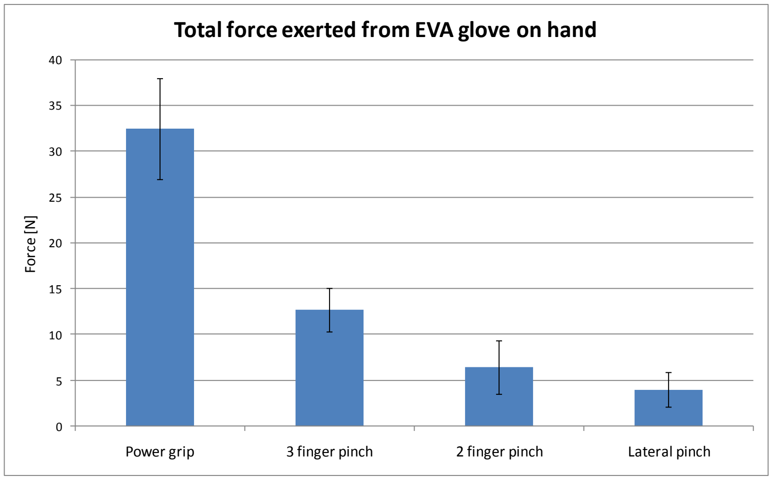

Figure 13. Total force exerted from EVA glove on subject's hand.

Figure 14 shows an example of pressure mapping on the hand for gloved (a) and bare-handed (b) condition in the closed hand configuration of the power grip movement. Each white area corresponds to a sensing array positioned on the hand; the position of the white areas in the picture represents quite clearly its position on the hand. Basically, the sensing areas are three each on the index, middle finger, ring finger and little finger; two on the thumb; one across the palm corresponding to the metacarpo-phalangeal joints; two (a rectangular and an L-shaped one) on the

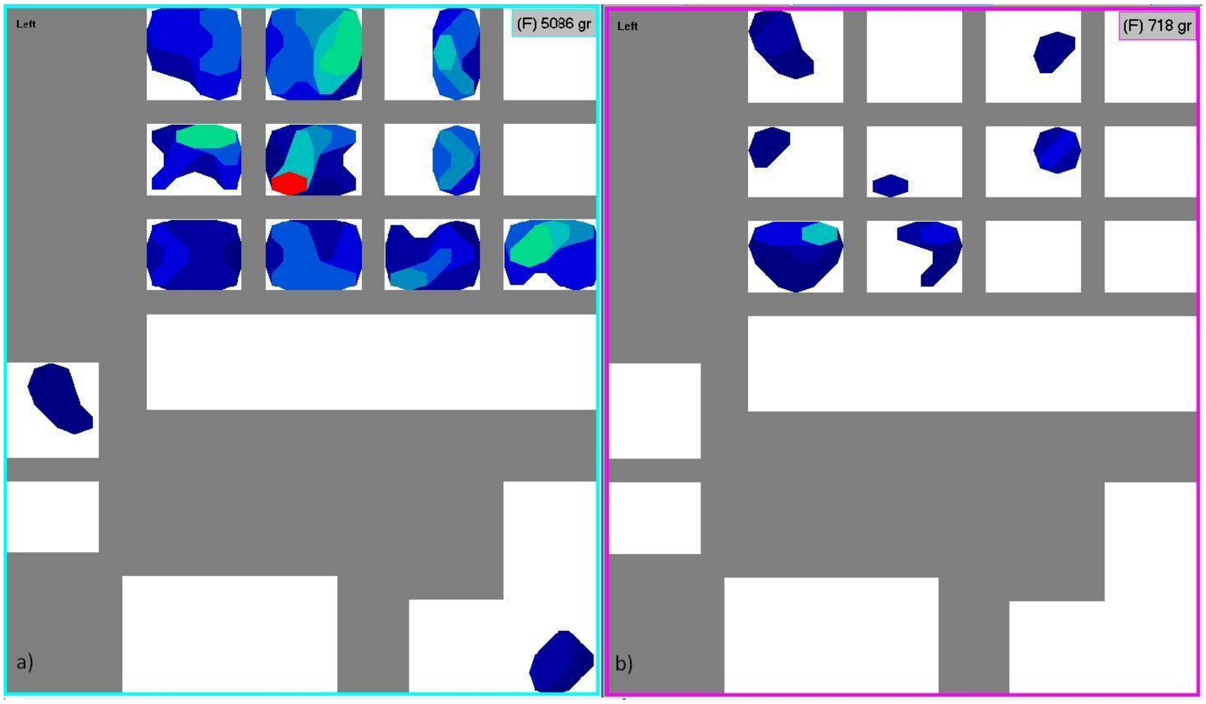

Figure 14. Pressure distribution in power grip movement wearing EVA glove (a) and bare-handed (b).

lower part of the palm. Pressure level is proportional to color, from dark blue (low pressure) to red (high pressure). The number on the upper right of each frame is the value of the total force acting on the hand (the integral of all pressures on the hand surface). Bare-handed conditions present some colored areas, due to the bending effect of the sensors. For the gloved power grip, it is evident how most resistance arises on the fingers: this is due to the contact between fingers and glove while bending, but also to the stiffness of the glove. Small areas with particularly high pressure levels are also very interesting because they could be an indication of potential local sores and discomfort. To confirm this, the tests should be repeated on a larger number of subjects, to see if higher pressure areas have the same localization for all subjects. If not, the pressure peak could be due to the particular hand geometry of the subject or to imperfect fitting of the glove.

IV. Conclusions and Future Work

This study provides many indications on how and how much wearing an EVA glove hinders human hand performances. Very interesting is the fact that effects are strongly correlated to the kind of task. Deeper research is required, though, to obtain a thorough knowledge of these effects. In particular, investigation on exerted forces (by means of grip and pinch dynamometers) would give absolute strength values and not only percentages of performance decay with respect to each subject's maximum voluntary contraction.

Future work should comprise the study of different tasks, involving different hand movements, and also involving tools and common EVA tasks. Also, both these and future tests should be repeated wearing a pressurized glove, for which we are acquiring a specific glove box. Furthermore, a deeper research on fatigue can be achieved by means of surface EMG during task performance. Finally, it would be interesting to repeat the tests on different EVA gloves and with different pressurizations.

Acknowledgments

The authors would like to thank all volunteer subjects who participated in the study.

References

[1] C. Walz, M. Gernhardt, "Extravehicular Activity – Challenges in Planetary Exploration" *3rd Space Exploration Conference & Exhibit*, Denver, Colorado, February 2008

[2] Rigutti A., *Atlante di anatomia*, ed. Giunti S.p.A., Firenze – Milano, 2000, pp. 28 – 29; 86 – 87.

[3] O'Hara J.M., Briganti M., Cleland J., Winfield D., "Extravehicular Activities Limitations Study. Volume II: Establishment of Physiological and Performance Criteria for EVA Gloves-Final Report" Report number AS-EVALS- FR-8701, NASA Contract no NAS-9-17702, 1988.

[4] R.R. Bishu, G. Klute, "The effects of extra vehicular activity (EVA) gloves on human performance" *International Journal of Industrial Ergonomics* vol. 16, 1995, pp.165-174

[5] M. H. Welsh, D. L. Akin, "The Effects of Extravehicular Activity Gloves on Human Hand Performance" *31st International Conference on Environmental Systems*, Orlando, FL, July 2001

[6] S. Rajulu, E. Benson, S. England, M. Mesloh, S. Thompson, "Use of Traditional and Novel Methods to Evaluate the Influence of an EVA Glove on Hand Performance" *40th International Conference on Environmental Systems*, Barcelona, Spain, July 2010

[7] D.C. Buhman, J. A. Cherry, L. Bronkema-Orr, R. Bishu, "Effects of glove, orientation, pressure, load, and handle on submximal grasp force" *International Journal of Industrial Ergonomics* vol. 25, 2000, pp. 247-256

[8] S. Thompson, M. Mesloh, S. England, E. Benson, S. Rajulu "The Effects of Extravehicular Activity (EVA) Glove Pressure on Tactility" *54th Annual Meeting of the Human Factors and Ergonomics Society*, San Francisco, CA, September 2010

[9] M. Mesloh, S. England, E. Benson, S. Thompson, S. Rajulu "The Effects of Extravehicular Activity (EVA) Glove Pressure on Hand Strength" *3rd International Applied Human Factors and Ergonomics*, Miami, FL, July 2010

[10] Skoog, A. I., Abramov, I. P., Russian spacesuits, Springer-Verlag, New York, 2003, chap. 5.

[11] A.H. Mishkin, B.M. Jau, “Space-Based Multifunctional End Effector Systems: Functional Requirements and Proposed Designs” Techical Report 88-16, NASA JPL, 1988

[12] http://www.tekscan.com/