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Effects of EVA gloves on grip strength and fatigue under low temperature and low pressure

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ABSTRACT

Objective: To study the effects of wearing extravehicular activity (EVA) gloves on grip strength and fatigue in low temperature, low pressure and mixing of two factors (low temperature and low pressure).
Methods: The maximum grip strength and fatigue tests were performed with 10 healthy male subjects wearing gloves in a variety of simulated environments. The data was analysed using the normalization method.
Results: The results showed that wearing gloves significantly affected the maximum grip strength and fatigue. Pressure (29.6, 39.2 kPa) had more influence on the maximum grip compared with control group while low temperatures (−50, −90, −110 °C) had no influence on grip but affected fatigue dramatically. The results also showed that the maximum grip strength and fatigue were influenced significantly in a compound environment.
Conclusions: Space environment remarkably reduced strength and endurance of the astronauts. However, the effects brought by the compound environment cannot be understood as the superimposition of low temperature and pressure effects.

1. Introduction

Strength is the source of manual performance, and under the control of the brain it can realise precise manual performance by contraction force from the upper body and muscles of various hands parts. Up to 90% of actions in extravehicular activity (EVA) are performed by the upper body (Zhang et al., 2011). However, astronaut operation strength during extravehicular activity decreased dramatically due to the combined effect of glove pressure, low temperature and glove structure (Ding et al., 2005). Therefore, in the development process of EVA gloves, the major problem is how to maintain necessary strength during extravehicular activity. Endurance and strength are always considered together in the experiments because enough physical strength is the premise to complete the work. A reduction in strength and fatigue will lead to additional energy expenditure and fatigue, and a result could be a serious accident.

Scholars have studied various elements affecting hand strength from different perspectives. Geng researched the influence of low temperature on performance from aspects of subjective feelings and finger temperature measurements when in touch with low-temperature objects (Geng et al., 2001); Aldien illustrated the pressure distribution of the hand-handle operation interface by studying hand forces and handle size (Aldien et al., 2005). As far as the study of an EVA glove is concerned, Buhman showed the influence of the glove on maximum grip strength from glove structure, pressure, load, handle structure (Buhman et al., 2000). However, they only conducted single-factor analysis of each element, and the influence of low temperatures was not included. Tsaousidis studied the effects of gloves on maximum force and the rate of force development in pinch, wrist flexion and grip (Tsaousidis and Freivalds, 1998). By low-pressure chamber experiments, Bishu established the maximum limits of strength and fatigue when performing all kinds of tasks with gloves, which was manifest in the relationship between strength and fatigue (Bishu et al., 1995). Francisco studied the relationship between strength and dexterity by dynamic pinch performance (Valero-Cuevas et al., 2003). However, these studies mainly focused on single-factor effects on strength. There has been no definite conclusion on the

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interaction (addition, subtraction or combination) of glove pressure, low temperature and glove structure on strength, which is the real condition of EVA.

Therefore, this article studies hand strength under the combined influence of glove strength and low temperature and takes maximum grip strength and grip fatigue as essential evaluating indicators.

2. Methodology

2.1. Subjects

Ten male volunteers from university joined this experiment. The length of their hands was 18 ± 0.3 cm. The width of hands was 10.5 ± 0.2 cm. They were all right-handed and volunteered to participate in the experiment.

2.2. EVA glove

We used a replica of an EVA glove from the Astronaut Centre of China to conduct the tests. It had two parts: pressure glove and TMG. During the EVA, it was a part of the spacesuit. The pressure inside the clothing was constant. The pressure between the inside and outside of the glove was 29.6 (US)/39.2 (Russia) kPa. The test on the ground could simulate pressure differential only because of gravity. However, the state of the glove was similar. For specific content, refer to section 2.5 and Fig. 1.

2.3. Experimental settings design

The experiment included three variables: pressure, ambient temperature (AT), and grip bar surface temperature. Therefore, the experiment had five groups (Table 1). The first one was the control group, where the environment and grip bar temperature were 25 °C, and pressure was 0. This group was mainly used for comparison with other data. Group I simulated different pressures (22.1/29.6/39.2 kPa) (Ding et al., 2005), but the other variables were the same. These pressures were standard stamping data for EVA gloves. The variables in Group II were the same as the control group, except the grip bar surface temperature (−50/−90/−110/−130 °C). We designed this group because grasping low temperature objects was a common action in EVA activities. According to the literature, the surface temperature of objects in space is between −50 and −130 °C (Zhang et al., 2011). Group III simulated a compound environment in which the pressure and the temperature changed. The pressure was 39.2 kPa, grip bar surface temperature was −50/−110/−130 °C, and the other variable was the same as the control group. We determined this pressure because this study mainly focused on the Chinese EVA glove. In Group II, we found that there was no significant difference between −50 and −90 °C, so we ignored −90 °C in Group III. In order to simulate an environment closer to the real EVA, we designed Group IV to compare with the Group III data. In Group IV, the EVA gloves would be put in a −50 °C environment. The pressure was 39.2 kPa, and the grip bar temperature was −50 °C. At this point, heat loss occurred at both the palm side and back side of the glove, and the surface temperature of the hand fell even faster.

Table 1
Study design under different pressure and temperature.

No.	Pressure (kPa)	AT (°C)	Grip bar temperature (°C)
Control group	0	25	25
I	22.1/29.6/39.2	25	25
II	0	25	−50/−90/−110/−130
III	39.2	25	−50/−110/−130
IV	39.2	−50	−50

All the tests were performed when subject was wearing gloves.

2.4. Measurement

2.4.1. Strength

According to the ways of force imposed by hands in manual work, hand strength can be divided into grip, pinch and twist. Grip strength is caused by bending all the fingers together except the thumb. Pinch results from squeezing between fingertips. Different from grip and pinch, a twist completes work by the resulting moment and is relevant to the friction coefficient of the object surface. This article chose maximum grip strength as the object of study because strength studies of EVA gloves were often based on hand-handle interface with grip strength as the main method. Moreover, according to Chen's research (Chen et al., 2006), a correlation did exist among grip, pinch and twist, thus grip could be used in tests in place of the other two forces.

2.4.2. Grip fatigue

Muscle fatigue may occur after long-time exertion of force, and in turn it will affect normal operation. Fatigue has a direct relationship with operation strength and time, namely work power.

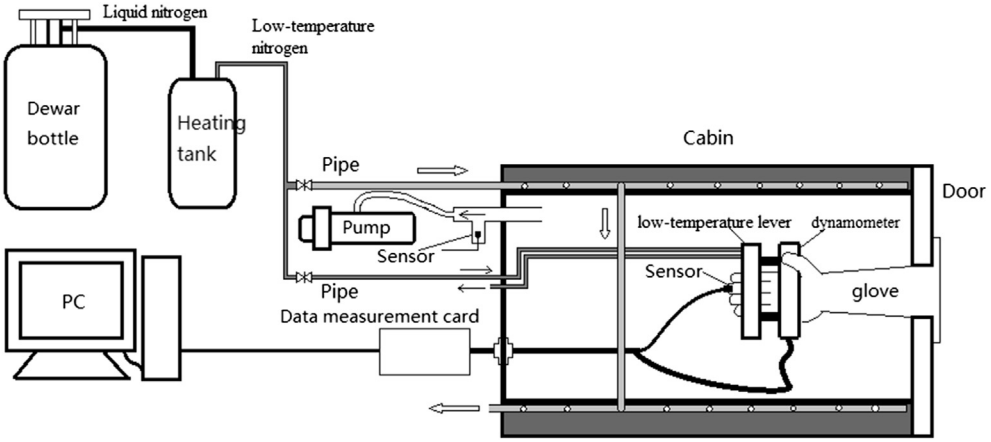

Fig. 1. Low-temperature simulation cabin and measurement equipment.