



Effects of EVA glove on hand dexterity at low temperature and low pressure

Yinsheng Tian^a, Haibo Zhang^b, Li Wang^c, Li Ding^{a,*}, Deyu Li^a

^a School of Biological Science and Medical Engineering, Beihang University, Beijing, China

^b AVIC Aerospace Life-support Industries, Xiangfan, China

^c China Astronaut Research and Training Center, Beijing, China

ARTICLE INFO

Keywords:

EVA glove
Dexterity
Low temperature
Pressure
Finger temperature

ABSTRACT

Hand dexterity is an important index to assess whether extravehicular activity (EVA) gloves are appropriately designed. Pressurized gloves and low temperature environments can both cause a decrease in hand dexterity. However, due to the difficulty in performing tests under extreme conditions, there has been no report on dexterity tests with gloves under pressure and low temperature. To fill this gap, we performed a dexterity test of EVA gloves with twelve male volunteers involved under the extreme conditions, which were created in the low-pressure simulation cabin with vaporized liquid nitrogen used to cool it down. A total of nine conditions were designed. Purdue pegboard test and nut fastening test were improved before being applied in a hand dexterity test. Completion times for both tests, finger temperatures and cold feeling of the hand were recorded and analyzed. Results showed that the completion times for both tests increased either as the temperature decreased or as the pressure increased. Furthermore, a combined effect of low temperature and pressure was observed. The study provides evidence in support of astronaut training and optimization of EVA glove productivity.

1. Introduction

Up to 90% of astronauts' actions in extravehicular activities (EVA), such as assembling or maintaining equipment, were performed with the upper limb (Zhang et al., 2011). Therefore, the EVA glove design is a major concern which greatly impacts astronaut's operational efficiency (Bishu et al., 1994). In the past 40 years, the standard of ergonomic evaluation of EVA gloves has been continuously improved and formed a complete evaluation system (O'Hara et al., 1988; Ding, 2005; Chen et al., 2006, 2007; Tian et al., 2016). Manual dexterity has been defined as a motor skill that is determined by the range of motion of arm, hand, and fingers and the performance of some hand operations. It is a combination of reaction time, sensibility, nerve conduction, grip strength, time to exhaustion, and mobility. There are two main factors that affect the hand dexterity when putting the gloves on: gas pressure in the glove (abbreviated as Pressure), and low temperature at the fingers due to the lack of warming compartments in the gloves (abbreviated as Low temperature).

The Pressure can cause a pressure difference between the inner and outer layers of the Glove and it will make the inner layer (airtight layer) inflated, and hence the joints become difficult to bend (O'Hara et al., 1988). During the first spacewalk in 1965 by USSR, the cosmonaut was hardly able to return to the spacecraft because of an unbalanced clothing pressure. Therefore, a large amount of investigations focused

on pressure. In the 1960s, some scholars initiated studies on the operation performance of pressurized EVA gloves, mainly concentrating on the operating time (Bradley, 1969). Bishu and colleagues (Bishu and Klute, 1995) systematically studied the hand dexterity when wearing pressurized EVA gloves. They carried out tests on the strength and dexterity in men and women respectively and evaluated the performance of both hands at different levels of pressure. Hu et al. (2008) and Thompson et al. (2011) investigated the effect of pressure on dexterity and concluded that it caused an obvious reduction in dexterity.

Low temperature often occurs when an astronaut is shaded from the sun. The surface temperature of space suits often drops to a very low temperature (−100 °C to −50 °C). As a result of the protection of the thermal micro-meteoroid garment (TMG) layer of EVA gloves, the finger temperature will be maintained above 5 °C, which still corresponds to the acceptable range of the human body. However, as the spacewalk gets longer, the spacesuit is also required to maintain a higher performance under a low temperature in order to keep astronauts' manual ability (e.g. dexterity) as well as safety. It was reported that hand dexterity starts to be affected when finger temperatures are at 20 °C and important loss of dexterity occurred at 15 °C and below (Hellström, 1965; Schieffer et al., 1984; Daanen et al., 1993). Ducharme et al. (1999) tested blood flow and manual dexterity of fingers during cold exposure. They found that finger blood flow was also a critical factor to maintain finger dexterity in the cold. Muller et al. (2014)

* Corresponding author. Beihang University, 37 Xueyuan Road, Haidian District, Beijing 100191, China.
E-mail address: ding1971316@buaa.edu.cn (L. Ding).

conducted the Purdue pegboard test in a cold environment (5 °C) and also measured core temperature, hand pain, and thermal sensation. They observed that hand dexterity declined when the finger temperature decreased. This suggested that if the hand was exposed to low temperature for a long time, manual operating capacity would be gradually lost and difficult to recover. Therefore, in a low temperature environment, keeping a stable hand and body temperature above a certain level is an important guarantee for maintaining operational capacity. In space, it mainly relies on the spacesuit insulation and heating devices.

However, there are many difficulties in assessing the dexterity of EVA gloves in ground experiments. One question is that the experimental environment is difficult to simulate. The pressure difference of EVA gloves has been simulated using a low-pressure simulation cabin (Bishu et al., 1994) owing to the difficulty in achieving vacuum, but cooling the gloves is a big challenge. Technically speaking, cooling the fingers is much easier and more affordable than cooling gloves because the latter requires refrigerant liquids with lower boiling points (such as liquid nitrogen). Therefore, cooling the bare hand becomes a major simulation method. Many cooling methods were used in the past: cold water (Cheung et al., 2003), wind (Daanen and Hein, 2009) or low-temperature simulation cabin (Muller et al., 2010). However, the indirect low-temperature simulation methods did not consider the effect of gloves on manual operations, and could not be combined with the current low-pressure simulation experiments. It is not possible to study possible combined effects of temperature and pressure using direct hand cooling methods. So, this is one of the main reasons for the lack of research on dexterity in combined factors. Another question is: what should be the most appropriate method of evaluation? Hand operation performance can be assessed by counting the operation time or the error rate. At present, the Purdue pegboard test is the most commonly used for hand dexterity test (Tiffin et al., 1948; Ducharme et al., 1999; Cheung et al., 2003; Muller et al., 2010). Hand dexterity is scored as the number of metal pins that can be placed in small holes within 30 s using the finger and thumb. Screw plate test was also frequently used (Lockhart, 1968; Schieffer et al., 1984), which consists in measuring the number of nuts mounted on screw within a specified period. Other hand dexterity tests can be mentioned: Minnesota rate of manipulation placing (MRMP) tests, Knot rope test (Ding et al., 2005). How to apply the dexterity evaluation test to the environment simulation experiment of EVA glove is also an issue that cannot be neglected.

The aim of the present study was to investigate the effects of both low temperature and pressure on hand dexterity when wearing a EVA glove. Liquid nitrogen was used to cool a low-pressure cabin to simulate both pressure and low temperature conditions to evaluate dexterity. Through the statistical analysis of experimental results of Purdue pegboard test and Nut fastening test, a preliminary conclusion how the two combined factors affected dexterity was obtained.

2. Methods

2.1. Volunteers

12 male volunteers (23.4 ± 2.5 years old) who were selected according to the criteria of 50th percentiles population in hand size. All participants were students from Beihang University, they were all in good health and were all right-handed. Before participating in the experiment, they gave informed consent.

2.2. Low temperature and low-pressure environment simulation

The Low-pressure simulation cabin for EVA gloves (see Fig. 1) consisted of two parts: cylindrical metal cabin and the plexiglass door. When the door was closed, the cabin had a good sealing condition (leakage < 50 ml/min). The gas in the cabin was pumped through the channel on the cabin into the external environment. The pressure of the

cabin could be controlled by measuring the air pressure in the channel in real time by a vacuum gauge (DZA1, YunJie, China). There was a hole in the center of the door that allowed the EVA glove to pass through and fixed to the door. The gas pressure in the Glove was a constant (101 kPa). Knowing the glove surface pressure which was the pressure of the cabin P_c (kPa), the EVA glove actual pressure P_g ($P_g = 0.29.6$ or 39.2 kPa) was then pressured difference $101 - P_c$.

In order to simulate the low-temperature environment at the same time, the copper tubes were wrapped on the outer surface of the cabin, and the vaporized liquid nitrogen was injected into the tubes to cool the container, thereby cooling the gas inside the cabin. The temperature of the gas could be measured in real time by the temperature sensor arranged at the center of the cabin. By adjusting the flow rate of liquid nitrogen, the temperature in the low-pressure cabin could be controlled. EVA glove surface temperature would drop along with the cabin temperature and consequently affected the temperature of the layers of the Glove. When the cabin temperature became stable, it was assumed that the temperature of the glove surface equaled to the cabin temperature. As the cabin did not reach the vacuum state, the cooling was mainly achieved through conduction and convection, so the cooling time was longer than the actual situation. Due to the limited capacity of liquid nitrogen, the experimental conditions could be maintained during 30–90 min depending on different cabin temperatures. Therefore, the experiment was organized by the test conditions. One condition was tested with all volunteers each time. Moreover, the low temperature could reduce the sealing of the low pressure cabin. It was therefore very difficult to simulate the condition with low temperature and low pressure in the cabin.

A test glove was designed for simulating EVA gloves in the present study. There was essentially no differences in the structure and material between the test Glove and the Gloves used by the astronauts. Thermal and mechanical properties were also similar. The only difference was that the test glove had the possibility of adjusting the length of the fingers to fit the hand size from 25th to 75th percentile of Chinese (GB/T 10000-1988).

2.3. Other experimental apparatus

Three types of data were collected: completion times for dexterity tests, finger temperature and subjective rating score of the cold.

2.3.1. Dexterity

The dexterity was assessed by analyzing the times for completing Purdue pegboard and nut fastening tests under different conditions. The traditional method has a disadvantage: due to the limited operating space of the cabin, it was not possible to complete the two tests in succession. It was necessary to open the door to replace the device after completing one test. The standard measuring devices were too large and could not be placed in the low-pressure cabin, so in this study we improved the measuring equipment and methods.

Purdue pegboard test: The device consisted of two parts, i.e. one pin and a board with slots. The pin was cylindrical with a cross-section size of 10 mm and a length of 100 mm. The board had two slots (20 mm apart) which could make the pin be adequately inserted. Each slot had two states: it was occupied when the pin was inserted, otherwise it was idle. The status of the slot changed as the pin moved. Participants were asked to pull out the pin and insert the idle slot using the thumb, index and middle fingers. This was considered as one count. With the stopwatch (YM3-14-128, Kulv, Beijing, China), the total time to complete 10 counts was recorded for each test condition. The test was repeated three times. The average time of completing 10 counts was retained.

Nut fastening test: The test was carried out using a screw plate. The screw plate contained three components: a plate, a screw welded to the plate, and a matching nut. The screw had a diameter of 20 mm and a length of 45 mm. During the pre-tests, it was found very difficult to screw the nut using two or three fingers in low temperature and

Download English Version:

<https://daneshyari.com/en/article/6947599>

Download Persian Version:

<https://daneshyari.com/article/6947599>

[Daneshyari.com](https://daneshyari.com)