Optimizing the physical ergonomics indices for the use of partial pressure suits

Li Ding a, Xianxue Li a,*, Alan Hedge b, Huimin Hu c, David Feathers b, Zhifeng Qin d, Huajun Xiao d, Lihao Xue d, Qianxiang Zhou a

a Key Laboratory for Biomechanics and Mechanobiology of Ministry of Education, School of Biological Science and Medical Engineering, Beihang University, No. 37 XueYuan Road, Haidian District, Beijing 100191, China
b Department of Design & Environmental Analysis, College of Human Ecology, Cornell University, Ithaca, NY 14853, USA
c China National Institute of Standardization, No. 4 ZhiChun Road, Haidian District, Beijing 100088, China
d The 4th Dept., Institute of Aviation Medicine of Air Force, Chinese People’s Liberation Army, Beijing 100036, China

A R T I C L E   I N F O

Article history:
Received 3 December 2013
Accepted 27 August 2014
Available online 19 September 2014

Keywords:
Partial pressure suit
Manipulative mission
Ergonomics index system

A B S T R A C T

This study developed an ergonomic evaluation system for the design of high-altitude partial pressure suits (PPSs). A total of twenty-one Chinese males participated in the experiment which tested three types of ergonomics indices (manipulative mission, operational reach and operational strength) were studied using a three-dimensional video-based motion capture system, a target-pointing board, a hand dynamometer, and a step-tread apparatus. In total, 36 ergonomics indices were evaluated and optimized using regression and fitting analysis. Some indices that were found to be linearly related and redundant were removed from the study. An optimal ergonomics index system was established that can be used to conveniently and quickly evaluate the performance of different pressurized/non-pressurized suit designs. The resulting ergonomics index system will provide a theoretical basis and practical guidance for mission planners, suit designers and engineers to design equipment for human use, and to aid in assessing partial pressure suits.

© 2014 Elsevier Ltd and The Ergonomics Society. All rights reserved.

1. Introduction

Personal protective clothing (PPC) is equipment used to ensure the safety of wearers in extreme environments, such as high altitude, low-pressure conditions for pilots and high-temperature environment for firefighters. Williams et al. (1997) performed a series of experiments to study the influence of chemical protective clothing during various activities of sailors. When they marched at medium speed with heavy backpacks, it was found that the chemical protective clothing not only limited their flexibility and field of vision but also decreased cognitive performance, including prolonged reaction time and increased number of physical and cognitive errors.

In order to evaluate the performance of a new style of protective suit for firefighters, Coca et al. (2008) studied a series of ergonomics indices, such as the wearer's range of movement, ability to accomplish tasks, and comfort. They analyzed the ergonomic qualities of the clothing by comparing the variation of each ergonomics index under two conditions: wearing a new prototype firefighter ensemble (PE) with additional chemical/biological hazard protection and a standard ensemble (SE). They found that in spite of design features to enhance chemical/biological hazard protection, the PE design does not decrease the wearer's overall functional mobility compared to the SE. However, subjects seem to be more comfortable wearing the SE compared to the PE. These overall findings support the need for a comprehensive ergonomic evaluation of protective clothing systems to ascertain human factors issues. Berson (2002) found that pressurized clothing restricts the wearers' movement when inflated, affecting control of the ambulance and ability to perform emergency operations.

In order to increase the ability of pilots to efficiently fly within a U-2 cockpit, movement-related indices should be considered in the design phase of PPS. O’Hearn et al. (2005) studied the influence of Army cold weather clothing’s operating dexterity as well as physical security and comfort. Based on their research, they established ergonomics evaluation methods and an ergonomics index. However, this clothing is used on the ground environment and is very different with pilot's PPS. Partial pressure suits (PPSs) are one type of personal protective clothing designed to ensure the safety of pilots when flying at high altitudes (Hu et al., 2008b). A PPS is worn...
by pilots to protect them from both high altitude hypoxia and hyperventilation. It is a potentially life saving piece of equipment when coupled with a high-altitude oxygen-supply protection system (Kozloski, 1994). A PPS utilizes the mechanical forces and ergonomics of the clothing to provide counter pressure for the body surfaces. As a result, the negative effects on the body from a pressurized oxygen-supply can be reduced, providing greater endurance (Berglund and Marklund, 2005).

In recent years, with the improved performance of fighter planes, the protective capability requirements of PPS have increased as well, leading to concerns about the tradeoffs between a PPS's function and efficiency (Færevik and Eidsmo Reinertsen, 2003; Murray et al., 2011). Ergonomics research on high-altitude partial pressure suits (PPSs) can provide evidence to develop an optimal ergonomics index that can be used to evaluate the design of PPS. Past research (Adams and Keyserling, 1996; Hu et al., 2008a, 2007; Liu et al., 1998) on PPS neglected two vital aspects: (1) The lack of a valid index system for PPSs based on engineers' design of partial pressure suits (PPSs) can provide evidence to develop an ergonomics evaluation index system that is primarily based on human mechanics and anatomy. (2) The lack of research on optimization of a PPS ergonomics evaluation index. In order to increase efficiency while minimizing the costs and time for PPS evaluation, it is essential to optimize an index system to increase its practicality and functionality.

The present study focuses on optimization of an ergonomics evaluation index system. This system has three interrelated levels. Level 1 includes three ergonomics indices, level 2 includes 10 ergonomics indices and level 3 includes 23 ergonomics indices. Since there are many indices in this system, it would be too time-consuming to measure and analyze all of them, especially since some of them cannot be measured in a limited time frame. For example, when a PPS is pressurized, the wearer has only a short time before breathing becomes a problem due to external positive pressure, which would make it difficult to complete the required measurements. Therefore, the present research optimized the ergonomics evaluation index system using regression and fitting analysis. In this way it provided a more convenient and efficient way to evaluate the ergonomics performance of PPS.

A series of ergonomics experiments on PPSs were conducted to establish this systematic evaluation to improve the flight performance of pilots, their ability to perform tasks efficiently in a PPS and the ergonomics design of the human—machine interface in an aircraft cockpit.

2. Methods

2.1. Subjects

Based on pilot recruitment standards of China, twenty-one healthy right-handed Chinese males were recruited for this study. Females were not recruited since most pilots in China are male. The demographics and anthropometric parameters of the subjects are listed in Table 1.

2.2. PPS

Two different types of clothing were tested: conventional clothing (CC) and the partial pressure suit (PPS). The casual attire consisted of shorts and a vest, while the PPS was a capstan anti-G and counter pressure suit widely used by pilots (Fig. 1).

Table 1

<table>
<thead>
<tr>
<th>Items</th>
<th>Mean</th>
<th>Std.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr.)</td>
<td>23.14</td>
<td>1.20</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>169.48</td>
<td>2.73</td>
<td>165</td>
<td>175</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>62.52</td>
<td>4.99</td>
<td>56</td>
<td>77</td>
</tr>
<tr>
<td>Leg length (cm)</td>
<td>90.81</td>
<td>2.93</td>
<td>84</td>
<td>97</td>
</tr>
<tr>
<td>Lower leg length (cm)</td>
<td>39.86</td>
<td>2.67</td>
<td>34</td>
<td>44</td>
</tr>
<tr>
<td>Shoulder width (cm)</td>
<td>40.52</td>
<td>1.57</td>
<td>38</td>
<td>44</td>
</tr>
<tr>
<td>Knee width (cm)</td>
<td>9.89</td>
<td>0.93</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Ankle width (cm)</td>
<td>6.37</td>
<td>0.63</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Chest circumference (cm)</td>
<td>91.71</td>
<td>4.15</td>
<td>84</td>
<td>101</td>
</tr>
<tr>
<td>Thigh upper circumference (cm)</td>
<td>55.24</td>
<td>2.55</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Trunk upper circumference (cm)</td>
<td>166.19</td>
<td>5.09</td>
<td>158</td>
<td>176</td>
</tr>
<tr>
<td>Upper arm length (cm)</td>
<td>31.24</td>
<td>1.95</td>
<td>28</td>
<td>34</td>
</tr>
<tr>
<td>Lower arm length (cm)</td>
<td>25.38</td>
<td>0.74</td>
<td>24</td>
<td>27</td>
</tr>
</tbody>
</table>
دریافت فوری متن کامل مقاله

<table>
<thead>
<tr>
<th>ISI Articles</th>
<th>مرجع مقالات تخصصی ایران</th>
</tr>
</thead>
</table>

- امکان دانلود نسخه تمام متن مقالات انگلیسی
- امکان دانلود نسخه ترجمه شده مقالات
- پذیرش سفارش ترجمه تخصصی
- امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- امکان دانلود رایگان ۲ صفحه اول هر مقاله
- امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- دانلود فوری مقاله پس از پرداخت آنلاین
- پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات