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

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ABSTRACT

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.

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

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Nomenclature

PPC	personal protective clothing
TP	target pointing
PDV	pull down the veil
DBL	drawing-back a leg
CJ	controlling-joysticks
AT	accomplishing time of task
B	buttons
BS	buttons and switches
RWRA	right wrist bar thumb side
RWRB	right wrist bar pinkie side
RKNE	right knee
RANK	right ankle
LELB	left elbow
RELB	right elbow
RSHO	right shoulder
TP1	AT of right arm with B group for TP
TP2	AT of left arm with BS group for TP
TP3	AT of right arm with BS group for TP
TP4	inverse orientation AT of right arm with BS group for TP
PPS	partial pressure suit
PDV1	movement of RWRA for PDV
DBL1	flexion angle of RKNE joint for DBL
DBL2	movement of RANK for DBL
CJ1	pushing forward of RWRA for CJ
CJ2	pushing left of RWRA for CJ
CJ3	pushing right of RWRA for CJ
RS1	maximum vertical movement of RELB for lateral lift
RS2	maximum vertical movement of RELB for forward extension
RS3	maximum vertical movement of RELB for backward extension
RS4	maximum horizontal movement of RELB for adduction
RS5	maximum horizontal movement of RELB for abduction
RS6	range of motion of RSHO in the coronal plane
RE1	motion angle of RELB joint
RH1	movement of RKNE
RH2	range of motion of right hip joint
RW1	movement of LELB
RW2	movement of RELB
GS1	maximum grip strength

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 safe and ergonomic protective wear. To date, there have been no studies researching indices based on human mechanics and anatomy. Therefore, it is useful to establish an integrated and valid ergonomics evaluation index system for PPSs that is primarily based on the environment, cockpit layout, flight operation tasks, 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
The mean anthropometric data for all of the subjects.

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