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The Gravity-Loading countermeasure Skinsuit (GLCS) and its effect upon aerobic exercise performance

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A R T I C L E I N F O

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A B S T R A C T

The Russian Pingvin suit is employed as a countermeasure to musculoskeletal atrophy in microgravity, though its 2-stage loading regime is poorly tolerated. The Gravity-Loading Countermeasure Skinsuit (GLCS) has been devised to comfortably compress the body via incrementally increasing longitudinal elastic-fibre tensions from the shoulders to the feet. We tested whether the Mk III GLCS was a feasible adjunct to sub-maximal aerobic exercise and resulting VO_2Max predictions. Eight healthy subjects (5♂, 28 ± 6 yr) performed cycle ergometry at 75% VO_2Max (derived from an Astrand-Rhyming protocol) whilst wearing a GLCS and gym clothing (GYM). Ventilatory parameters, heart rate (H_R), core temperature (T_C), and blood lactate (B_L) were recorded along with subjective perceived exertion, thermal comfort, movement discomfort and body control. Physiological and subjective responses were compared over TIME and between GYM and GLCS (ATTIRE) with 2-way repeated measures ANOVA and Wilcoxon tests respectively. Resultant VO_2Max predictions were compared with paired *t*-tests between ATTIRE. The GLCS induced greater initial exercise ventilatory responses which stabilised by 20 min. H_R and T_C continued to rise from 5 min irrespective of ATTIRE, whereas B_L was greater in the GLCS at 20 min. Predicted VO_2Max did not differ with ATTIRE, though some observed differences in H_R were noteworthy. All subjective ratings were exacerbated in the GLCS. Despite increased perception of workload and initial ventilatory augmentations, submaximal exercise performance was not impeded. Whilst predicted VO_2Max did not differ, determination of actual VO_2Max in the GLCS is warranted due to apparent modulation of the linear H_R-VO_2 relationship. The GLCS may be a feasible adjunct to exercise and potential countermeasure to unloaded-induced physiological deconditioning on Earth or in space.

1. Introduction

Typical 6 month missions to the International Space Station (ISS) are associated with significant multi-systems de-conditioning including bone demineralisation [1], muscle atrophy [2,3], cardiovascular (contributing to aerobic) de-conditioning [4,5] and spinal elongation with associated back pain [6]. Such changes during longer missions could severely impact health and functionality upon return to Earth (1Gz) or when landing in a partial Gz environment such as Mars.

Current engagement of exercise countermeasures on the ISS includes usage of equipment such as the T2 treadmill, Cycle Ergometer with Vibration Isolation and Stabilisation System (CEVIS) and Advanced Resistive Exercise Device (ARED) as part of the overall health maintenance system [7,8]. Approximately 2.5 h in duration is spent on exercise countermeasures each day, including setup, 60 min for aerobic exercise (e.g ergonometry), 40–60 min for ARED exercise, data transfer and stowage [7]. Typically, in-flight VO_2Max, estimation is via extrapolation of the heart rate (H_R) response to sub-maximal upright ergometry in 1Gz prior to flight, based on the established positive linear relationship between H_R and VO_2[9].

Although more recently loss of muscle mass and strength has been attenuated within 6-month ISS missions [10,11], such protocols still do not fully protect against weightlessness-induced physiological de-conditioning for all individuals, and more importantly, such countermeasure devices would not be logistically feasible for manned missions to other celestial bodies. Thus, in preparation for exploration missions to Mars (which may take three years), a newer generation of passive countermeasures are sought, that have greater efficacy but require

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Fig. 1. The traditional Pengvin suit (left) and the Mk III Gravity-Loading Countermeasure SkinSuit (GLCS; right).

fewer resources (time, volume, mass, and energy) are required [12].

Recently, the Gravity-Loading Countermeasure Skinsuit (GLCS) has been developed using bi-directional elastic weave technology in an attempt to provide progressive axial loading equivalent to that on Earth when standing [14]. Whereas the Pingvin suit has a leather belt that allows for a 2-stage garment, the GLCS uses each circumferential fibre of the elastic weave as a 'belt' to produce numerous vertical stages. These stages gradually increase in elastic tension along the longitudinal body axis from the shoulders to the feet. In addition, the circumferential fibres act as tethers with very low circumferential tension to prevent suit slippage (Fig. 1). The GLCS has been designed to integrate with other exercise countermeasures to improve the magnitude and comfort of impact load delivery [14], and may offer other benefits such as spinal elongation amelioration. However, whether the GLCS can be worn during astronauts' daily activities, including exercise countermeasures is yet to be determined. Previous work has shown that the Mk III GLCS (Fig. 1) provides stepwise ~0.7Gz axial loading and is viable to incorporate with resistance-based exercise [15].

Thus, the aims of this study were to determine the feasibility of GLCS-wear integrated with prolonged submaximal aerobic exercise at 75% VO_2Max, as performed on the ISS. A secondary aim was to investigate resultant VO_2Max predictions based on GLCS-induced H_R responses.

2. Methods

Eight healthy subjects (5♂, 28.4 ± 5.9 yr, 182.6 ± 9.7 cm and 77.3 ± 8.3 kg) gave written informed consent to participate in the study that received approval from King's College London Ethics Committee (BDM/11/12–106). Subjects denied taking any medication or having any history of neurological, cardiorespiratory and/or psychological disorders. None of the subjects were in pain, pregnant and/or lactating, nor had consumed alcohol for 24 h and food for 2 h, prior to testing. Testing took place in a quiet, thermo-neutral (~24 °C) environment.

2.1. Experimental design

All subjects were provided with a custom-fabricated (total mass ~0.360 kg) Mk III Gravity Loading Countermeasure Skinsuit (GLCS; Costume Works Inc, Boston, Massachusetts, USA) and appropriately sized flat-soled cycling shoes. Each participant attended a suit fitting session during which 63 anthropometric circumferential measurements from the armpit to the ankle were obtained to calculate the material strain required to generate an ~1Gz regime. One month later subjects attended the laboratory once a week for three consecutive weeks; week 1 was a familiarisation session, followed by two further visits for aerobic testing in loose fitting gym (GYM) clothing and the personalised GLCS.

2.2. Familiarisation

The familiarisation session involved donning and doffing the GLCS to ensure adequate fit in addition to estimation of 75% VO_2Max via completion of a 7-min submaximal Åstrand-Rhyming test [5] on a cycle ergometer (Monark Cycle Ergometer, Ergomedic, Sweden) in loose fitting clothes, whilst heart rate (H_R) was determined via a standard 3-lead ECG (Lifepulse, HME, UK). Participants commenced cycling at 50 W (60RPM) followed by increments of 25 W every 2 min; until a steady state H_R between 130–160 bpm was observed. The Åstrand & Rhyming nomogram was then used to calculate the power output (W) required to achieve 75% VO_2Max according to the age and gender of the subject for subsequent aerobic testing (GYM and GLCS).

2.3. Experimental protocol

Following a period of 2 min rest for baseline data collection, each aerobic testing session comprised of a single 20-min cycling bout, at the pre-determined power output (75% of predicted VO_2Max); on an upright cycle ergometer (Monark, Sweden), performed in GYM and GLCS. In the GLCS, stirrups were strapped around the pedals to apply the available loading via the soles of the cycling shoes. During cycling, H_R (BPM), expiratory flow (through a secured oro-nasal mask with Hans Rudolph pneumotachography, USA), and expired gas concentrations (AD Instruments Respiratory Gas Analyser, Australia) were continuously recorded. Core temperature ($T_{C;\ °C}$) recordings were obtained by ingestion (30 min prior to testing) of a telemetric pill (CorTemp, HQinc, USA) and finger prick blood lactate (B_L) concentration (mmol L^{-1}; SuperGL, Dr Muller, Germany) at baseline (after 3 min of rest) and at 5 min intervals during exercise. Subjective ratings of perceived exertion (RPE [16]), thermal comfort (ASHRAE Thermal Comfort and Adaptive 7-point scale [17]), body control (Modified Cooper-Harper scale [18]) and movement discomfort (Modified Corlett and Bishop scale [19]) were also collected at REST, and every 5 min during exercise.

2.4. Data analysis

Physiological data was sampled at 1 kHz (Powerlab ADC, LabChart 7.1, AD Instruments, Australia) with breath-by-breath data extracted to yield 1 min means (± SEM) for minute ventilation (V_E; L.min; BTPS), mass corrected oxygen consumption (VO_2; ml.kg.min^{-1}; STPD) and carbon dioxide production (VCO_2; L.min; BTPS), in addition to T_C and H_R. All physiological parameters were compared over TIME – from rest to 5 min, and 5–20 min - and between ATTIRE (GYM and GLCS) across these time points via two-way repeated measures ANOVA. Bonferroni corrected *post-hoc* paired *t*-tests were used to identify where significance lay in the instance that TIME, ATTIRE, and TIME*ATTIRE interaction effects were present. Estimated VO_2Max – calculated using the mean H_R from the final min of each exercise bout via the Astrand & Rhyming nomogram method – were compared between GYM and GLCS via paired *t*-tests. Subjective measurements were also compared as per the physiological parameters, albeit with (non-parametric) wilcoxon tests. Statistics were performed using SPSS (19.0, SPSS Inc., Chicago, IL, USA) with significance defined as $p < 0.05$.