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A harness for enhanced comfort and loading during treadmill exercise in space

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ABSTRACT

Introduction: Locomotor and some resistance exercises in space require a gravity replacement force in order to allow 1g-like ground reaction forces to be generated. Currently bungee cords, or other loading devices, interface with the crew member through a harness with a waist belt and shoulder straps. Crew members often find the application of the required loads to be uncomfortable, particularly at the hips.
Methods: An experimental harness was built that differed from previous in-flight designs by having a wider, moldable waist belt and contoured shoulder straps with additional padding. Eight subjects ran at 100% body weight (BW) loading for a total duration of 30 min per day on 12 days over a 3-week period in simulated 0-g conditions using horizontal suspension. A 100 mm Visual Analog Scale (VAS)[1] was used to assess harness-related and lower extremity discomfort at the end of each run.
Results: The overall rating of harness discomfort decreased from 27 mm on the 100 mm scale on day 1 to 10 mm on day 12, with significant decreases recorded for the back and hip regions as well as the overall harness.
Discussion: The experimental harness allows for repeated exposure to 30-minute bouts of 100% BW loaded simulated 0-g running with levels of discomfort less than 30 mm on a VAS scale of 0–100 mm. We believe that the use of such a harness during on-orbit exercise countermeasures may allow exercise to be performed at levels which are more effective in preventing bone and muscle loss.

1. Introduction

Treadmill exercise has long been prescribed on Mir, Space Shuttle, and International Space Station (ISS)[2] missions as a potential countermeasure to the musculoskeletal and cardiovascular changes that are encountered during spaceflight [1,2]. Like the original treadmill designed by Dr. William Thornton in 1973 and tested on Space Shuttle [3], all treadmills flown in space share a requirement that the subject be tethered to the treadmill via bungees or other loading mechanisms, collectively known as Subject Load Devices (SLDs) [3]. These SLDs provide a "gravity replacement" to accelerate the crew member back towards the treadmill belt.

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[1] VAS-Visual Analog Scale.
[2] ISS-International Space Station.
[3] SLDs-Subject Load Devices.

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The load provided by the SLD is applied to the body via a harness which typically consists of a hip belt and shoulder straps with interconnecting components. Prior to our experiment, there were two types of harnesses designed for use with the ISS Treadmill with Vibration Isolation and Stabilization (TVIS)[4] (Fig. 1a and b). Both harnesses have a waist belt with inserts that can be adjusted to accommodate crew member girth, and shoulder straps which can be lengthened or shortened. Only minimal padding, comprised primarily of aramid felt and Nomex (DuPont, Wilmington, DE) cloth, is provided in both shoulder straps and hip belts in either of the existing designs which are 'one size fits all' and not truly customizable to fit the body of individual crew members.

The total load applied by the SLDs through the harness determines the magnitude of the forces under the feet during ground contact, and the SLD load therefore represents the primary determinant of the "dose" of mechanical load that is delivered during walking or running in microgravity. The load measured at the feet is a surrogate measure for forces on all other anatomical structures in the chain between the shoulders and the feet. Crew members have described the standard ISS TVIS harness as varying from "uncomfortable" to "unbearable" and that it gave them "hot spots" and "rubbed them raw" [4], and the need for a more comfortable harness has been indicated [5].

In experiments on the ISS between November 2002 and April 2006 during Increments 6–12 of the ISS program, we measured in-shoe reaction forces during walking and running exercise on TVIS and these averaged only 75% and 54%, respectively, of 1-g values [6]. Debriefing of crew members by the senior author indicated that discomfort in the ISS TVIS harness that linked the SLD load to the body could be intense, particularly during running, and this appears to be an important reason why lower than 1 BW SLD loads were used. The extent of TVIS use was highly variable among the crew member participants, ranging from 39 to 121 sessions during the study's 181 ± 15 days, due in part to equipment availability, exercise prescription, and individual preference [6]. It is very likely that harness discomfort played a role in the "individual preference" component of this variability.

Previous studies have examined the comfort of running while wearing a harness under varied SLD loads in simulated microgravity [7,8]. Notably, a replica of the ISS TVIS harness with a modification which dictated equal load sharing between the hips and shoulders was used to apply loads of up to 100% BW to subjects running at $3.35\ \mathrm{m\ s^{-1}}$ (7.5 mph) [8]. Subjects in the study by Genc et al. [8] rated their shoulder discomfort to be the highest of the measured regions, due in part to the waist belt of the replica ISS TVIS harness which had a non-rigid felt core that was slipping off the subjects' hips causing a majority of the load to be shifted to the shoulders. Excessive shoulder loading appears to have been an issue during on-orbit TVIS running where a crew member describing running on TVIS like "running with dumbbells on your shoulders" [4].

In the present paper we describe the design and assessment in simulated microgravity using horizontal suspension of a new treadmill harness (experimental harness) which borrows heavily from technology used in commercial backpacks. Although the backpack industry specializes in designs which interface bulky loads to the body, the magnitude of the target loads for such products are considerably less than those required for the simulation of 1-g locomotion in microgravity. For example, a commercial backpack with a carrying capacity of 70 lbs (31.8 kg) is considered "heavy duty" [9] while a U.S. Marine with full combat equipment and rations carries loads between 87 and 130 lbs (39.5–59 kg or $0.51–0.76 \times$ BW for a 170 lb person) [10]. Nevertheless, we hypothesized that an experimental harness could be designed to allow the user to run for typical treadmill exercise bouts on successive days with no more than mild discomfort. A typical treadmill exercise bout was defined by observations of ISS exercise by Station crew members [11]. We also hypothesized that discomfort would decrease with exposure to the 1 BW loading over the 12 sessions. The work described in this paper is foundational to the new ISS treadmill harness that is currently available to crewmembers.

2. Methods

2.1. Harness design

There is a maxim in the backpacking community that "the ideal distribution (of load) is about 70–80% of the weight on (the) hips" and the remainder on the shoulders [9,12], although this remains largely untested. It has been suggested that a heavy-duty waist belt, as found on a multi-day backpack, should be able to comfortably support up to 90% of the total load [13]. It has also been suggested that a properly fitted waist belt should transfer the majority of the load to the pelvis [12].

The principles that guided the design of the experimental harness were: (1) maximizing load on the hips while; (2) sharing load between the shoulders and hips (3) reducing pressure over bony prominences; (4) minimizing resistance to ventilation; (5) increasing comfort over the neck and shoulders and; (6) minimizing compression of the breasts of female users.

A review of available technology in the commercial backpack sector identified two products that had the potential to meet the above criteria when combined with other components. These were the cupped, sex-specific, variable-size, moldable Bioform CM waist belts from Osprey Packs (Cortez, CO) (Fig. 1c and d) and broad, well padded, polyethylene foam bi-layer, variable-size, sex-specific contoured "S"-shaped shoulder straps from Kelty (Boulder, CO) (Fig. 1c and d). The women's waist belts were more canted over the hips in order to provide a better fit and load on the pelvis. The women's shoulder straps were narrower, and the "S"-curve began higher up the strap.

Previous designs have applied load at discrete points at the hip which tended to pull the waist belt away from the body, detracting from the overall fit of the harness. In the experimental harness, we applied load via a cupped waist

[4] TVIS-Treadmill with Vibration Isolation and Stabilization.