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SUBJECT LOAD-HARNESS INTERACTION DURING ZERO-GRAVITY TREADMILL EXERCISE

Jean L. McCrory, Heidi A. Baron, [1]Janice A. Derr, [2]Brian L. Davis, and Peter R. Cavanagh

Center for Locomotion Studies , Department of Kinesiology and [1]Statistical Consulting Center
Penn State University, University Park, PA 16802

[2]Department of Biomedical Engineering, The Cleveland Clinic Foundation, Cleveland, OH

INTRODUCTION

When astronauts exercise on orbit, a subject load device (SLD) must be used to return the subject back to the supporting surface. The load in the SLD needs to be transferred to the body by a harness which typically distributes this load between the pelvis and the shoulders. Through the use of a zero-gravity simulator, this research compared subject comfort and ground reaction forces during treadmill running at three levels of subject load (60%, 80%, and 100% of body weight) in two harness designs ("shoulder only" and "waist and shoulder ").

REVIEW AND THEORY

Exercise will almost certainly play an integral part in minimizing the adverse effects of space travel on the body, particularly bone mineral loss and muscular atrophy. It is hypothesized that an effective exercise regimen would elicit loads on the lower extremities that resemble those encountered on Earth (Cavanagh, 1986; Convertino and Sandler, 1995). No testing has been done in space to quantify the ground reaction forces to which the lower extremities are exposed, but it is believed that these forces are much less than those experienced in 1-G (Cavanagh, 1987).

The Penn State Zero-Gravity Simulator (PSZS Davis et al. 1996), is a device which suspends subjects horizontally from multiple latex cords, with each cord negating the weight of a different limb segment. A treadmill mounted on the wall under the PSZS enables subjects to run in simulated zero-gravity. The SLD has, in the past, consisted of a set of 4 springs attached to a harness, with the waist of the subject feeling the entire pull of the SLD. With this system, the subjects could only tolerate an artificial gravity of 60% of 1-G (Davis et al. 1996). Astronauts currently wear a harness system in which the SLD pulls both at the waist and shoulders (Greenisen and Edgerton, 1994), although the tension in these springs has not been quantified. However, it is likely that previous SLDs have only provided loads less than Earth gravity (Cavanagh 1986, 1987).

The purpose of this study was to quantify ground reaction forces, subject load, and subjective ratings of comfort from subjects wearing one of two harness designs under loads of 60%, 80%, and 100% of body weight while running in the PSZS. The objective was to gain insight into the effectiveness of the present countermeasures against bone mineral loss and muscular atrophy in space.

PROCEDURES

Eight subjects (mean age 29.4 ±4.5 years, mean height 176.6 ±9.0 cm and mean mass 73.3±5.3 kg) participated in this study. Two harness configurations were assessed: a "shoulder only" design, in which 4 springs were attached to shoulder pads worn by the subject, and "waist and shoulder " design, in which 4 springs were attached to the shoulder pads and 4 to a waist harness. Three levels of load (60%, 80%, and 100% of body weight) were randomly administered in each harness design. Ground reaction forces were measured via a Kistler force plate mounted within the treadmill belt. Load cells measured tension in the SLD. A modified Borg scale was used to assess the levels of discomfort. Subjects ran at a speed of 1.96 m/s for 3 minutes during each condition. A period of 3 minutes rest was given between conditions. Data were collected at 500 Hz.

RESULTS

The level of discomfort increased significantly ($p<0.05$) as the subject load increased from 60% to 80% to 100% body weight. Also, on a scale from 0 (no discomfort) to 10 (excruciating pain), the maximum levels of discomfort at 100% BW load averaged 2.3 ± 0.6 in the "shoulder only" condition and 2.5 ± 0.8 in the "waist and shoulder " condition ($p<0.05$).

The following subject load variables were measured: maximum load, time to maximum load, minimum load, time to minimum load, average load, and load fluctuation. By definition, the subject loads were significantly different between the loading conditions of 60%, 80%, and 100% of body weight ($p<0.05$). When comparing the two harness designs, the "waist and shoulder " design resulted in a lower minimum load and average load, while the load fluctuation was greater ($p<0.05$). Selected load variables for the full body weight loading conditions are shown in Table 1.

Table 1: Subject Load variables during a 100% BW load.

Load Variables (% BW)	Shoulder Only	Waist & Shoulder
Maximum	112.6 ± 2.6	110.5 ± 3.0
Minimum	90.0 ± 2.5	70.8 ± 2.8
Average	101.4 ± 2.3	91.7 ± 2.7
Fluctuation	22.5 ± 1.3	39.7 ± 1.4

The following ground reaction force variables were measured: contact time, maximum impact force, time to maximum impact force, maximum propulsive force, time to maximum propulsive force, impulse, and loading rate. In both harness designs, the maximum impact force, maximum propulsive force, impulse, and loading rate were significantly different between loading conditions ($p<0.05$). Results for the "waist and shoulder " conditions are shown in Figure 1.

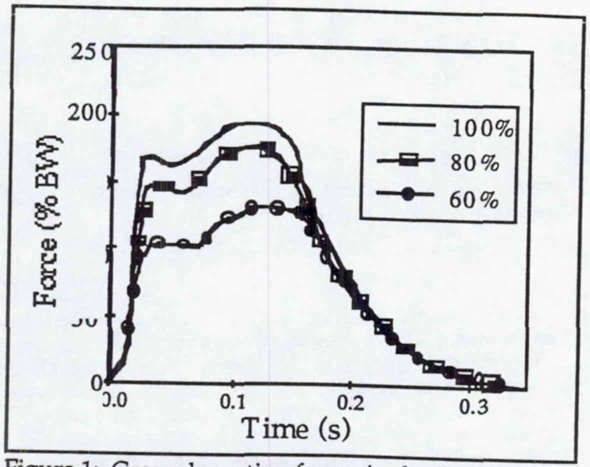

Figure 1: Ground reaction forces in the "waist and shoulder " condition in each of the subject loads.

When comparing the two harness designs, the maximum propulsive peak and the impulse were significantly greater in the "shoulder only " harness configuration ($p<0.05$). The ground reaction force curves at 100% load are shown in Figure 2.

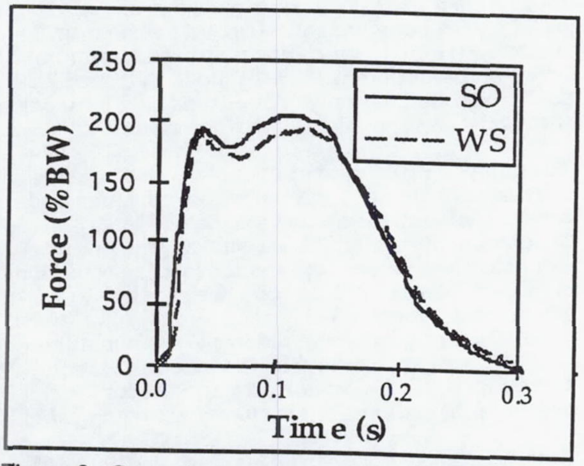

Figure 2: Ground reaction force curves at a load of 100% BW. (Harness design: SO= shoulder only, WS= waist and shoulder)

DISCUSSION

The clear dependence of peak reaction force on subject load is apparent from Figure 1. This highlights the importance of maximizing subject load if countermeasures are to generate 1-G like loads on the lower extremity. At 100% load, the peak ground reaction force was significantly greater for the "shoulder only" harness configuration. The amount of discomfort from the SLD and harness was perceived to be in the slight to moderate range at 100% loading. However, in both harness configurations, the shapes of the ground reaction force curves of subjects running in the PSZS were characteristic of the "groucho running" force curves reported by McMahon et al. (1987), indicating that the subjects were running in a slightly crouched (hips and knees flexed) position. This was most likely an attempt to reduce the discomfort caused by the SLD pulling on the body.

The effectiveness of tethering running as a countermeasure against bone mineral loss and muscle atrophy is believed to be dependent upon the presence of 1-G type forces. Unless a harness can be designed which will alleviate pressure felt at the SLD attachment sites, astronauts will tend to do "groucho running" to lessen the pain of the harness, thereby also attenuating the ground reaction forces. Another possibility is that the altered gait patterns result from subject loads which are locally applied (at the hips and shoulders) compared to the more global action of gravitation force.

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