External Load affects Ground Reaction Force Parameters Non-uniformly during Running in Weightlessness

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INTRODUCTION

Long-term exposure to microgravity induces detriments to the musculoskeletal system (Schneider et al., 1995; LeBlanc et al., 2000). Treadmill exercise is used onboard the International Space Station as an exercise countermeasure to musculoskeletal deconditioning due to spaceflight.

During locomotive exercise in weightlessness (0G), crewmembers wear a harness attached to an external loading mechanism (EL). The EL pulls the crewmember toward the treadmill, and provides resistive load during the impact and propulsive phases of gait. The resulting forces may be important in stimulating bone maintenance (Turner, 1998). The EL can be applied via a bungee and carabineer clip configuration attached to the harness and can be manipulated to create varying amounts of load levels during exercise.

Ground-based research performed using a vertically mounted treadmill found that peak ground reaction forces (GRF) during running at an EL of less than one body weight (BW) are less than those that occur during running in normal gravity (1G) (Davis et al., 1996). However, it is not known how the GRF are affected by the EL in a true 0G environment. Locomotion while suspended may result in biomechanics that differ from free running. The purpose of this investigation was to determine how EL affects peak impact force, peak propulsive force, loading rate, and impulse of the GRF during running in 0G. It was hypothesized that increasing EL would result in increases in each GRF parameter.

METHODS

Four subjects (2M/2F; 172.75 ± 11.14 cm; 73.18 ± 14.03 kg) ran at 3.13 m/s (7 mph) during 0G onboard NASA's KC-135 airplane and on the ground (1G). Vertical GRF data were collected at 250 Hz for 25 sec during multiple trials with a GRF-measuring treadmill (Kistler Gaitway, Amherst, NY).

During 0G trials, the subjects wore a harness attached to an EL. EL was provided by one or two bungees in series with one to five carabineer clips. EL was adjusted between trials by placing clips in series with the bungees. The bungee/clip setups were attached on each side of the harness at hip height. Bilateral dynamic loading forces were measured at 120 Hz with load cells (ELPS-T3E-500L, Entran Devices, Inc, Fairfield, NJ) placed inline with the EL configuration. The mean dynamic EL for each trial was calculated throughout the entire trial. During 1G trials, subjects ran without the harness and EL configuration.

Eight consecutive footfalls (4 left and 4 right) were processed from each trial. The eight footfalls were chosen from the middle of the trial when it could be assured that the subject had achieved the 3.13 m/s running speed. Forty-four trials were used in the analysis. All GRF data were conditioned at 40 Hz using a Butterworth filter to remove any artifact. Peak impact force, peak propulsive force, loading rate (peak impact force/time to peak impact force) and impulse were determined for each footfall. Trial means for all eight footfalls were computed for each GRF variable. All variables were normalized to subject body weight (BW).

Correlation analysis and standard linear regression were performed to assess the relationship of each GRF parameter to EL. An alpha level of $p<.05$ was chosen to denote significance. The regression equations were used to predict the EL necessary to replicate 1G mean values

RESULTS AND DISCUSSION

The mean dynamic EL magnitude ranged from .53 to 1.24 BW and was significantly correlated to all GRF parameters (see Table 1). The r^2 values reflect that the EL accounts for only part of the variance, suggesting that additional factors may affect the GRF.

During running in 0G, GRF increased with increases in EL; however, their responses were highly varied. For example, peak impact force increases almost twice as fast as peak propulsive force (regression coefficients 1.29 vs. .67) with increasing EL. No single EL during 0G running sufficiently replicates GRF generated in 1G. For example, a .91 BW EL would replicate the mean peak impact force in 1G, but an EL of 1.72 would be required to replicate 1G peak propulsive forces.

SUMMARY

When an EL is applied to a subject during running in 0G via a bungee system, GRF parameters increase as the load level increases. It also appears that the EL effect upon the GRF is not uniform – increasing EL does not increase each GRF parameter at the same rate. EL levels that create 1G-like GRF based on one parameter may over- or under-load the body based on another parameter. Studies that examine the kinematics of locomotion in 0G may explain why these effects occur. It is possible that different methods of applying EL during 0G running must be developed to better replicate 1G-like GRF.

REFERENCES

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Table 1: Correlations and regression coefficients relating mean dynamic EL (BW) to GRF parameters. All coefficients and correlations were significant ($p<.05$).

Variable	r^2	Regression Coefficient, B	Intercept	Mean 1G Value	Predicted EL for 1G Replication
Peak Impact Force (BW)	0.42	1.29	.66	1.84	.91 BW
Peak Propulsive Force (BW)	0.37	.67	1.22	2.37	1.72 BW
Loading Rate (BW/s)	0.41	51.97	11.80	46.38	.67 BW
Impulse (BW*msec)	0.54	164.14	163.79	372.57	1.27 BW