Simulating a Lunar Wall of Death (M-WALL) to Load the Musculoskeletal System

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Summary

Hypogravity reduces load on the musculoskeletal system which is known to lead to functional decline and most likely musculoskeletal deconditioning. Inspired from recent experimental study, this paper aims to explore, via predictive simulation, the requirements (or feasibility) of an exercise countermeasure for lunar inhabitants that mitigates and/or counteracts undesired physiological adaptations: the "wall of death" (M-WALL). A musculoskeletal modelling approach was used to simulate an individual running around a set of circular vertical walls. Predicted ground reaction forces were compared to Earth sprinting gait values to evaluate if such countermeasure could load the lower body in an effective manner.

Introduction

Despite the lack of direct evidence of long term hypogravity exposure on extraterrestrial planets and the lack of long term, human hypogravity simulations on Earth, hypogravity will conceivably negatively impact musculoskeletal health [1], constituting a key barrier to extended lunar missions. Current countermeasures fail to prevent functional decline[1], prompting exploration of novel solutions. One proposal posits that lunar inhabitants could run on the inside of vertical circular walls that are perpendicular to the lunar surface [2]. Using a weight support system to imitate hypogravity, researchers investigated the countermeasure, reporting predicted GRFs that supported its potential efficacy to load the musculoskeletal system through mechanotransduction, thus maintaining]musculoskeletal integrity. However, the optimal design of such countermeasure and its impact on the musculoskeletal system is difficult to assess on Earth. In-silico investigation, however, removes these limitations and allows for detailed assessment of joint loading. Therefore, this investigation employs a musculoskeletal modelling approach to quantify joint torques experienced by the exerciser during running on cylindrical walls, perpendicular to the lunar surface.

Methods

A torque driven musculoskeletal model with 37 DoF, and a foot-ground contact model [3] was implemented in OpenSim 4.5. A tracking simulation was set up and performed to explore model validity by tracking kinetics and kinematics from a previous overground sprinting case study (n=1)[3]. Subsequently, a predictive simulation was set up using a gravity constant within the simulation environment of 0.17g (lunar gravity) and a cylinder of radius 4.73m [2] was approximated using 100 half-spaces, creating a running surface. An initial estimation from the sprinting was used in the predictive simulation along with an estimated curvilinear trajectory of the pelvis, replicating the expected kinematics of curvilinear running. Tracking and predictive simulation kinematics and GRFs were created, simulating a single step during running on the inside of circular walls in lunar gravity.

Results and Discussion

For countermeasure simulations, pelvis residuals were less than 1N in the x, y and z translational DoFs. The runner began with a resultant velocity of 7.78 m/s, which is realistic for high velocity running. Peak flexion-extension torques during the step were 272 Nm, 124 Nm, 174 Nm for the hip, knee and ankle respectively. These appeared substantially different to overground sprinting simulation values (362 Nm, 281 Nm and 338 Nm). However, these values are congruent with torques calculated in lower velocity running [4] and consistent with the results in [2]. Peak vertical GRF force was greater in the overground sprinting (2893N) than the M-WALL (1143N). However, peak braking forces appeared similar in sprinting (-932N) and the countermeasure (-1350N). Thus, these results support the feasibility of completing the countermeasure and its potential to provide adequate stimuli to the musculoskeletal system, to maintain musculoskeletal integrity. If feasible, this low-cost countermeasure may also benefit the cardiovascular system, which is deconditioned by microgravity[1], although no evidence exists for hypogravity. Future study should aim to demonstrate a cyclic gait pattern through simulation of multiple steps with periodic kinematics. Next, muscle-driven simulations would provide insight into joint-reaction forces and provide an idea of expected muscle activity, allowing for a more complete evaluation of musculoskeletal loading.

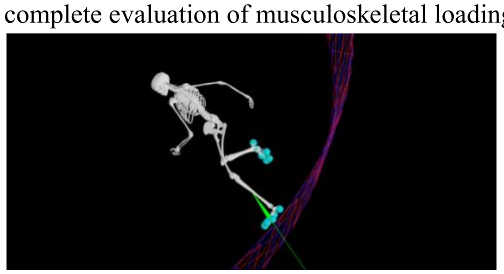

Figure 1: Visualisation of the model running on the M-WALL.

Conclusions

This preliminary investigation supports the feasibility of this countermeasure and its potential to mitigate hypogravity-related musculoskeletal decline. Future work should aim to optimize M-WALL design and employ methods such as head-up tilt bedrest to simulate the long-term effects of hypogravity before testing the M-WALL in vivo (as outlined in [2]).

References

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