Development of Walking Pattern Evaluation System for Hypogravity Simulation

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INTRODUCTION

The acceleration due to gravity at the surface of a planet varies directly as the mass and inversely as the square of the radius. This follows directly from Newton's law of universal gravitation.

The Moon is 384,403km distant from the Earth. Its diameter is 3,476km. The acceleration due to gravity is 1.62 m/s^2 because the Moon has less mass than Earth. It is approximately 1/6 that of the acceleration due to gravity on Earth, 9.81 m/s^2.

Mars and Earth have diameters of 6,775km and 12,775km, respectively. The mass of Mars is 0.107 times that of Earth. This makes the gravitational acceleration on Mars 3.73m/s^2, as expressed on Equation 1:

$$gm = 9.8 \times 0.107 \times (12775/6775)^2 = 3.73 m/s^2 \qquad (1)$$

Therefore, if a body weighs 200N on Earth, it is possible to calculate how much it would weigh on Mars. Knowing that the weight of an object is its mass (m) times the acceleration of gravity, we can have W = m x g; 200 = 9.8 x m; m = 20.41kg. This mass is the same on Mars, so the weight on Mars is Wmars = 3.73 x 20.41 = 76.1N.

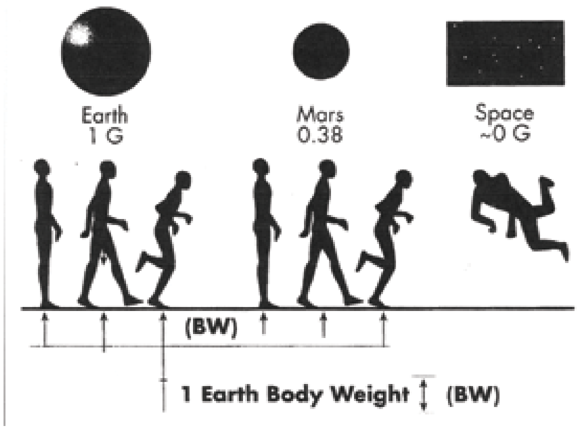
Figure 1 illustrates the change in body posture of an individual on Earth, on Mars, and in space (microgravity).

BACKGROUND

There are three primary techniques for simulating partial gravity: water immersion (neutral buoyancy), parabolic flight, and **body suspension device** (BSD) models.

Underwater Immersion. During tests, a neutrally buoyant subject is ballasted to simulate the desired partial gravity loading. For example, one-sixth of the subject's body mass is added in ballast if a lunar simulation is desired. Water immersion offers the subject freedom from time constraints and freedom of movement, but the hydrodynamic drag is disadvantageous for movement studies.

Figure 1. Schematic representation of body posture in different gravitational environments. (www.nasa.gov)



Parabolic Flight. NASA KC-135 aircraft or Russian IL-76 aircraft are typically used to simulate partial gravity by flying Keplerian trajectories through the sky. This technique provides approximately 30s and 40s for lunar gravity and Martian gravity tests, respectively. Parabolic flight is the only way to effect true partial gravity on Earth, but experiments are expensive and of limited duration.

Body Suspension Device (BSD) Models. BSDs have been developed and used worldwide to study human physiology during partial or total simulation, such as the Zero Gravity Locomotion Simulator (ZLS) (Cavanagh, McCrory, Baron & Balkin, 2002) and the Zero Gravity Simulator (ZGS) (D'Andrea & Perusek, 2005).

The Cleveland Clinic Foundation and Penn State University built the ZLS, which is mounted vertically in a freestanding frame and includes padded straps that support a runner under the head, torso, arms, and legs. In this position, there is no gravitational force between the runner and the machine.

In physiotherapy, body suspension devices provide patient and therapist security, giving increased freedom of movement to accomplish technical and facilitative maneuvers. Manual assistance is necessary to promote the postural adjustment in patients with neurological injury that uses a gait training system (Boehrman & Harkema, 2000).

Virtual reality offers potential for the development of evaluation and training systems, allowing precise control of a stimulus. Researchers have utilized gait training on a treadmill body suspension system with virtual reality. They found that people with multiple sclerosis increased the gait velocity, and their balance was improved after two months of treatment with the Body Weight Suspension and Treadmill (BWS/TM) system (Fulk, 2005). The virtual reality technology employed was based on navigation. Three virtual environments representing the soils of Earth, Mars, and the Moon were developed. The hypotheses were (1) the reduction of the gravitational force alters gait kinematic parameters; (2) the utilization of a Head Mounted Display (HMD), virtual reality glasses, while walking on a treadmill influences the postural balance of the user.

MAIN FOCUS OF THIS STUDY

The main objective of this research was to develop a secure and efficient system for **gait evaluation** that can be used for research purposes in aerospace medicine, physiotherapy, computer science, and rehabilitation medicine. A system was developed to evaluate **walking patterns** in **hypogravity simulation**, which was called SAMSH. This consisted of the improvement of a body suspension device and the instrumentation of a treadmill that served as a platform to assess a physical locomotion technique in a virtual environment.

Details of the equipment developed for this study are presented as follows:

The body suspension device (3000 mm x 2660 mm wide and 2000mm high) has a counterweight system of 20 bars (5kg each). The subject wore a harness (Advanced Air Sports Products; Lake Elsinore, CA), which was suspended by a steel wire and designed to support massive tensions (Figure 2). A load cell permitted the measurement of the mechanical stress by means of Wheatstone bridge.

Equation 2 demonstrates how to calculate the relative mass of a subject in a simulated gravitational field, where RM = relative mass (kg), BM = body mass on Earth (kg), SGF = simulated gravitational force (m/s^2) and 1G = 9.81 m/s^2.

Equation 3 gives the counterweight (CW, kg) necessary to simulate body mass for a preset hypogravity level.

$$RM = \frac{BM \times SGF}{1G} \qquad (2)$$