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Development of Walking Pattern Evaluation System for Hypogravity Simulation

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Abstract - This study aimed to develop a Walking Pattern Evaluation System during Hypogravity Simulation (SAMSH), which included the adaptation of a body suspension device, the instrumentation of a treadmill and the development of a virtual environment. SAMSH was developed using one subject. Kinematic analyses were performed whilst one individual was walking on the treadmill during body weight reduction simulating the gravitational forces of the Moon (reduction of 60%) and Mars (reduction of 30%) with and without virtual reality glasses (Head Mounted Display, HMD). The walking pattern was evaluated by means of knee and ankle electrogoniometers, foot switches placed on the front and back part of the plantar region, and five video cameras. Results showed that the body weight reduction during Moon simulation alter the walking pattern, including the increase in step time, contact time, step length and aerial time, and the decrease of walking cadence time (steps per minute). The findings of this study also suggested that hypogravity simulation reduces walking effort. The utilization of the HMD allowed the evaluation of the head position three-dimensionally during hypogravity simulation. The virtual environment reduced postural balance, due to the absence of visual input, which was evidenced by a protective extension reaction.

Keywords - Body Suspension Device, Hypogravity Simulation, Gait Evaluation, Virtual Reality, Walking Pattern.

I. INTRODUCTION

The main objective of this research was to develop a secure and efficient system for gait evaluation, which 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: 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.

The virtual reality technology employed was based on navigation. Three different 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 HMD (virtual reality glasses) while walking on a treadmill influences the postural balance of the user.

There are three primary techniques for simulating partial gravity: water immersion (neutral buoyancy), parabolic flight and body suspension, such as the Penn State Zero Gravity Locomotion (ZLS) [1] and the Zero Gravity Simulator (ZGS) [2]. In physiotherapy, body suspension devices provide patient and therapist security giving increased freedom of movement to accomplish technical and facilitatory maneuvers. Manual assistance is necessary to promote the postural adjustment in patients with neurological injury that uses a gait training system [3]. Virtual reality offers potential for the development of evaluation and training systems allowing precise control of a stimulus. Researches 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 BWS/TM System (Body Weight Suspension and Treadmill)[4].

II. METHOD

The body suspension device (3000 mm x 2660 mm wide and 2000mm high) has a counterweight system. The subject wore a harness (Advanced Air Sports Products; LAKE ELSEMORE, C.A.), which was suspended by a steel wire and designed to support massive tensions (Figure 1).
A load cell permitted the measurement of the mechanical stress by means of Wheatstone bridge.

Equation 1 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 2 gives the counterweight (CW, kg) necessary to simulate body mass for a pre-set hypogravity level.

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

$$CW = BM - RM \quad (2)$$

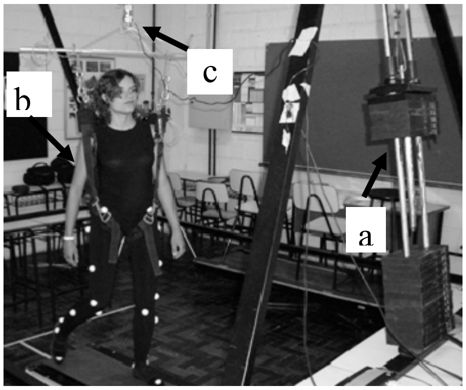

Figure 1: Body Suspension Device: counterweight system (a); harness used (b); the load cell (c).

A moving platform was based on the instrumentation of an electrical treadmill. The velocity of the treadmill was controlled using a communication protocol with a frequency inverter Movtrack07 (SEW). It was also necessary to develop an electrical interface RS232/485 to provide communication between the computer and the inverter. Treadmill velocity was at 40m/min throughout the tests (Figure 2).

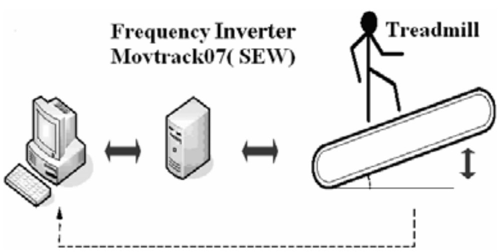

Figure 2: Electronic Velocity control of the treadmill

The toolkit Small VR (developed by the Virtual Reality Group of PUCRS, based on OpenGL and GLUT libraries) was developed to represent the Martian, Terrestrial and Lunar surfaces. MS visual C++ 6.0 software (C and C++ Programming Language) was used. The route followed by the subject was pre-determined. The subject was instructed to walk forward at 40m/min for approximately at the 2.15min. Dimensions for the virtual environment vertices were set at 10m by 10m. A proportional equation allowed the individual's height to be kept the same independently of his position, creating a realistic environment. Soil textures of Earth, Mars and the Moon were extracted from graphic computation libraries (Figure 3).

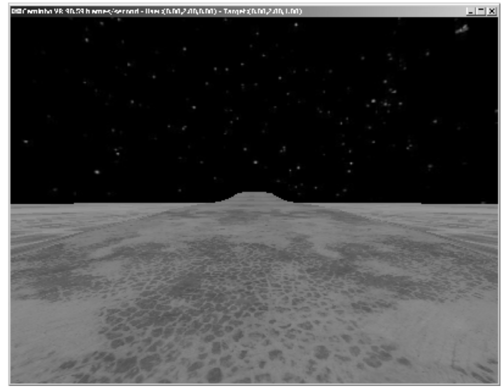

Figure 3: Virtual Mars environment

Kinematic gait was performed using spatial and temporal patterns. Electrogoniometers were used to evaluate the angular displacement of the knee and ankle (Figure 4, a). Each electrogoniometer consists of two aluminium bars, covered with rubber material, and connected by a 10KΩ potentiometer. They were fed by a 5V power source. Calibration was performed before the beginning of each experiment using a manual goniometer. Data was acquired by means of DataQ. The linearity of the electrogoniometers has been evaluate previously [5].

Foot Switches were developed for the measurement of temporal parameters that would determine the phases of the locomotion cycle. When a region of the foot was in contact with the surface, a short circuit supplied a level of tension that was captured by the DataQ and stored for subsequent processing (Figure 4, b and c).

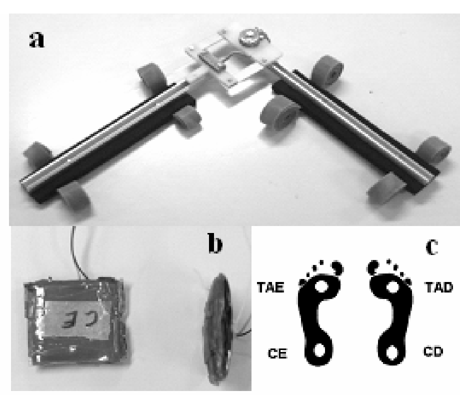

Figure 4: Electrogoniometer (a); Foot switches placed on the front (TAE, TAD) and back (CE, CD) part of the plantar region (b and c)

The subject experienced two different conditions of body weight reduction: 30% for

Mars and 60% for the Moon. Descriptive and angular variables related to kinematic gait evaluation were measured. Displacement of the subjects head into the three planes of movement were measured using the HMD (head mounted display), on x, y and z axes (Pitch, Yaw and Roll). The length, duration, speed of the stride, cadence and duration of the stance phase were recorded.

The stride time (TS) is the time between the first and the second contact of the same foot region on the ground. The stride length can be calculated using the equation ($v = d/t$). Cadence was determined by the number of steps per minute of the gait cycle. The stance phase could be determined by knowing the contact time (TC) of the feet regions instrumented by the foot switches. It was observed from the time between the initial and the final contact of each region (front and back part of the plantar region) of each foot during a stride. The aerial time (TA) is the time between the toe-off and ground contact of the opposite foot, representing the swing phase. This is more significant in hypogravity environments than at 1G [6].

Angular variables were evaluated by the electrogoniometers, which determine the ankle dorsal flexion (0º to 30º) and ankle plantar flexion (0º to 50º), flexion (-10º to 90º) and extension (90° to -10º) of the knee.

The statistical analysis was made using SPSS (version 10.0), ANOVA and t-tests. Significance level adopted was about 5%.

III. RESULTS

SAMSH adequately simulates the gravitational forces of Mars and the Moon for the study of the walking patterns in hypogravity environments. The use of electrogoniometers and foot switches allowed the evaluation of walking variables. Stride time, length stride and stance phase increased progressively from 1G to Mars simulation and then the Moon simulation. The opposite was observed in the cadence, which was higher at 1G and lower on the Moon simulation. Aerial time was 0,69s on the Moon, 0,63s on Mars and 0,50s on Earth.

Ankle dorsal flexion at Earth was 29º, increasing to 69.7º on Mars and to 67.9º on the Moon simulations. The ankle plantar flexion showed an opposite pattern, being bigger on the Moon and lower on the Earth. Flexion of the knee was 93.6º on the Moon simulation and 66.8º at Earth. The extension of knee was bigger on Earth (61.8º) and lower on the Moon (28.4º).

HMD data suggested that head movement was more prominent at the X axis (pitch, head up and down) on the Earth, Y axis (yaw, right and left inclination) on Mars simulation and Z axis (roll, left and right rotation) on the Moon simulation.

IV. DISCUSSION

This study suggests that the greater the reduction of body weight, the longer the stride time. This reflects findings in previous other studies [6]. Further, the time of contact diminishes with body weight reduction. During the simulation of the Moon steps were longer and less frequent than at 1G. A similar change in locomotion has been noted in aquatic environments [7].Reduction in subject body weight also influences ground reaction force [8]. There is a significant reduction in the peaks of force during locomotion in partial gravity [6].

Qualitative and quantitative data obtained by HMD and video cameras respectively, showed that head movements were predominantly on the z axis. Lateral trunk inclination was observed during body weight reduction (30% and 60%), as a result of limit movements of the trunk and pelvic region. This reflects findings of Rose and Gamble (1998) [9] who observed increased lateral trunk inclination in proportion with increases in stride length. A protective extension reaction, a postural reflex to avoid lost of body balance, was also observed with the utilization of HMD [10].

Kinematic evaluation of gait variables on Earth without HDM (control) were: speed 0.67 m/s, cadence 86 steps/min, length of stride 96 cm, knee angular variation 66.8º (flexion) and 5.2º (extension), ankle angular variation 27º between dorsal flexion (73º) and plantar flexion (100º). These results are similar to the ones obtained by Winter (1999) [11], who states that the normal speed at 1G should range from 1.16 m/s to 1.67 m/s. However, the gait speed in this research was slower in order to allow the subject to use the HDM safely. No data regarding walking patterns with virtual reality was found in the literature for comparison.

V. CONCLUSION

SAMSH proved to be effective in the simulation of different hypogravity environments.

The findings of this study suggest that hypogravity simulation reduces walking effort. The utilization of the HMD allowed the evaluation of the head position three-dimensionally during hypogravity simulation. The virtual environment reduced postural balance, due to the absence of visual inputs to the subject, which was evidenced by a protective extension reaction.

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