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EVALUATION OF EXTERNAL CARDIAC MASSAGE PERFORMANCE DURING HYPOGRAVITY SIMULATION

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ABSTRACT Preservation of astronaut crew health during an exploration mission to the Moon or Mars will be crucial to mission success. The likelyhood of a life threatening medical condition occuring during a mission to Mars has been estimated by NASA to be 1% per year [1]. Since basic life support is a vital skill in critical care medicine, plans must be in place for cardiopulmonary resuscitation in both microgravity and hypogravity (i.e. on the surface of the Moon or Mars).

Following the design of a body suspension device to simulate a hypogravity environment, subjects performed external chest compressions in 1G, 0.17G (Lunar), 0.38G (Mars) and 0.7G ('Planet X'). Chest compression adequacy was assessed by means of rate and depth. Heart rate immediately before and after 3 minutes of chest compression gave a measure of rescuer fatigue. Elbow flexion was measured using an electrogoniometer in order to assess the use of arm muscles to achieve chest compressions.

This study found that depth (Lunar and Mars) and rate (Mars) of chest compression was below American Heart Association recommendations during hypogravity simulation in the female group. Furthermore, elbow flexion proved to be significantly greater during Lunar and Mars hypogravity simulation than that of the 1G control condition, suggesting that upper arm force may be used to counter the loss of body weight in an attempt to maintain adequate chest compression under these conditions.

I. INTRODUCTION

A new initiative announced by the United States aims to resume manned lunar expeditions with a landing planned for 2015, and ultimately a manned mission to Mars [2]. The diagnosis and treatment of acute and chronic medical conditions have been identified by all space agencies as one of the highest priorities for both current orbital space flight and future exploration class missions to the Moon and Mars. There is a need for evidence-based guidelines and techniques for the management of medical emergencies during such missions [3].

Basic Life Support and Cardiopulmonary Resuscitation (CPR) are essential elements of current astronaut training. External chest compressions are a crucial element of CPR since they maintain adequate blood circulation to the brain and heart. The American Heart Association guidelines recommend a chest compression depth of 40-50mm at a rate of 100 compressions per minute is adequate [4].

NASA astronauts are currently trained in two external chest compression techniques for use in microgravity; the first utilizes the Crew Medical Restraint System to restrain both patient and provider; the second is the “Hand Stand” method [5]. Other methods have been evaluated, including the Evetts-Russomano technique developed by King’s College London, UK, and the Microgravity Laboratory, Pontifical Catholic University of Rio Grande do Sul (PURCS), Brazil [6]. However, hypogravity of different magnitudes will be experienced on planetary or lunar surfaces during future exploration class missions. Thus, CPR methods developed for terrestrial or microgravity conditions may not be applicable during the surface elements of such missions.

This study aimed to evaluate the performance of external chest compressions during hypogravity simulation of different magnitudes. Three gravitational environments were simulated; 0.17G (Lunar), 0.38G (Martian) and 0.70G (‘Planet X’). Planet X was created in order to provide an intermediate gravitational field to help with data analysis. External chest compression adequacy was studied, along with arm flexion during compressions.

This research provides insight into cardiac massage performance in hypogravity and helps to reflect on performance in clinical and training environments.

II. MATERIAL

Body Suspension Device: A method of simulating a reduced gravitational field has been developed by the Microgravity Laboratory / IPCT-PUCRS. The body suspension system comprises a body harness, counterweights and a load cell. The structure is pyramidal and consists of steel bars of 6cm x 3cm thickness. It has a rectangular base area of 300cm x 226cm and a height of 200cm. A steel cable connects the counterweights through a system of pulleys to a harness worn by the subject (figure 1).

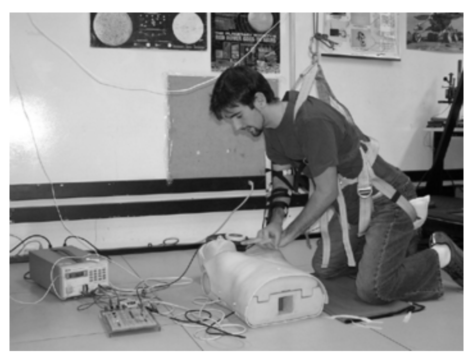

Figure 1. Male subject performing external chest compression wearing the harness for hypogravity simulation and the electrogoniometer attached to his right arm.

It uses a counterweight system made of 20 bars of 5kg each, placed opposite the subject. The necessary counterweights were calculated as follows; using equation 1 the relative mass of a subject in a simulated gravitational field can be calculated, 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, in kg) necessary to simulate body mass in a pre-set hypogravity level.

$$(1) \quad RM = \frac{0.6BM \times SGF}{1G}$$

$$(2) \quad CW = 0.6BM - RM$$

Basic Life Support Training Manikin: A standard full-body, CPR mannequin (Resusci Anne SkillReporter, Laerdal Medical Ltd, Orpington, UK) was instrumented for measurement of external chest compression depth and rate by the Microgravity Laboratory, PUCRS. A 10KΩ potentiometer was used for chest compression depth measurement, which gave a real-time feedback to the subject by means of a LM3941 component that shows a voltage variation by lighting a line of coloured LEDs (light emitting diodes), varying from 0 to 28 mm (red), 29 -39 m (yellow), 40 – 50 mm (green), 51-60 mm (red) (figure 2). Chest compression frequency was indicated by an electronic metronome set to a frequency of 100/minute.

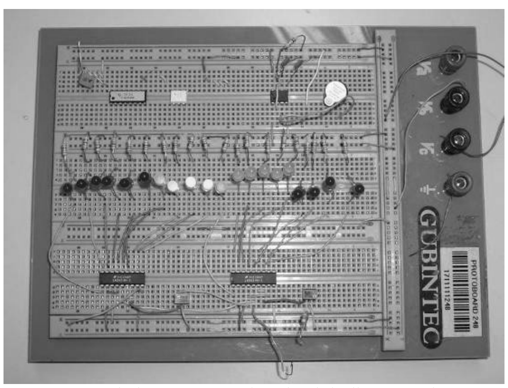

Figure 2. External chest compression depth indicator and metronome

Load Cell: A load cell was attached to the top of the pulley system in order to measure the corrected weight. The load cell consists of an Al 6351 aluminium tube (inner radius of 18mm, external radius of 32mm, depth of 22mm). The inner part of the tube contains a Wheatstone bridge made with strain gauges, which vary according to either compression or traction of the load cell. Calibration tests were performed to evaluate the linearity of the load cell. Two different weight loads (2kg and 17.45kg) were used for calibration before the beginning of each experiment.

Elbow Electrogoniometer: The angle of elbow flexion was measured using an electrogoniometer, which consists of two aluminium bars (20cm x 2.0cm x 0.3cm), covered with rubber material and connected by a 10KΩ potentiometer (figure 3). A 5V power source was used. Calibration was performed before the beginning of each experiment by attaching a manual goniometer to the electrogoniometer. The full range voltage at 0º and 90º was then recorded.

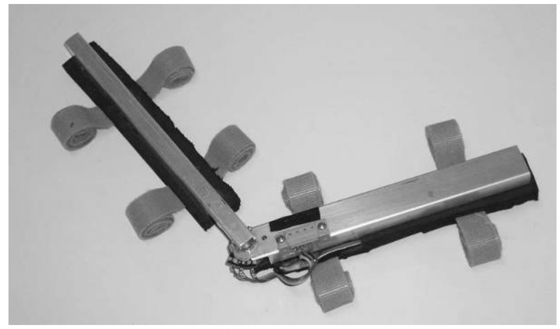

Figure 3. Elbow electrogoniometer

Data Acquisition System: A DataQ acquisition device (DATA-Q Instruments Inc, Akron, OH, USA) with 8 analogue and 6 digital channels, 10 bits of measurement accuracy, rates up to 14400 samples per second and USB interface was used. It supports full scale range of ±10V and a resolution of ±19.5mV. WinDaq data acquisition software allowing for conversion of Volts to the necessary unit was used. Three channels were used during data collection: depth and rate of chest compression, the amplified Wheatstone bridge signal of the load cell and the elbow electrogoniometer signal (figure 4).

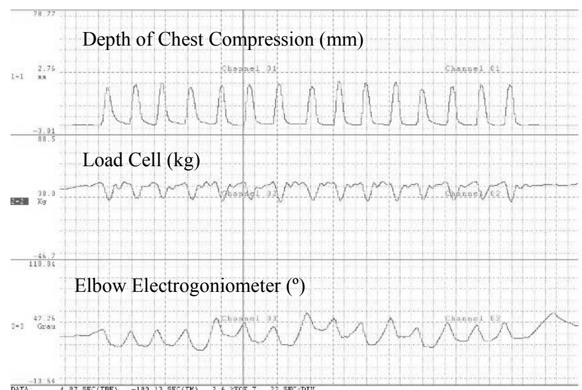

Figure 4. Windaq during Data Collection

III. Methodology

External cardiac compression measurements were obtained from 10 men and 10 women. Subject characteristics are outlined in Table 1. Subjects followed a protocol of 15 chest compressions alternating with 10s of rest for a total of 3 minutes. The 10 second rest simulated the time that would be taken for the provision of two mouth-to-mouth ventilations.

A 5 minute training session was carried out by all subjects. On different days, a control phase of 3 minutes at 1G was followed by 3 minutes of either one of three randomized levels of hypogravity simulation: 0.17G (Lunar gravity), 0.38G (Mars gravity) and 0.7G (´Planet X´).

During each visit, subject weight and height were measured prior to instrumentation with the body suspension harness and elbow electrogoniometer. Pulse heart rate was measured before and immediately after the completion of the chest compressions. Adequacy of external chest compression was assessed by means of chest compression rate and depth.

The study protocol was approved by the PUCRS Research Ethics and Scientific Committees. Each subject provided written informed consent before participating in the experiment.

Statistical analysis was performed using student t-tests and two way ANOVAs assuming a level of significance of 5%.

IV. Results

Subject characteristics are shown in Table 1. Subjects were matched for age and body mass index.

Table 1

	Male Mean Value ± SD	Female Mean Value ± SD	p value
Age (yr)	24 ± 1.64	26 ± 5.65	0.162
Height (m)	1.81± 0.03	1.65 ± 0.07	0.000
Weight (kg)	74.2 ± 10.58	57.1 ± 6.53	0.000
BMI (Kg/mm)	23 ± 3.09	21 ± 3.04	0.139

Subject characteristics. BMI: body mass index.

In all subjects, heart rate increased following 3 minutes of external chest compression. There was a trend towards the magnitude of this increase in heart rate to be greater in the female group (table2).

Table 2

	Male Mean ±SD	Female Mean ±SD
Resting HR (bpm)	83 ± 5.49	93 ± 8.94
Planet X Final HR	99 ± 17.58	124 ± 12.40
P value	0.018	0.000
Mars Final HR	102 ± 13.11	123 ± 8.62
P value	0.002	0.000
Moon Final HR	103 ± 21.61	129 ± 8.49
P value	0.009	0.000

Subject heart rate responses to 3 minutes of external chest compression. HR = heart rate, SD: standard deviation. P value represents the difference between resting heart rate and final heart rate at each hypogravity level.

The rate of chest compressions was not different between 1G and hypogravity in the male group (figure 5, Table 3). However, there was a trend towards chest compression rate being slower in the female group in hypogravity as compared with 1G (figure 5, Table 4). Similarly, male subjects maintained an adequate chest compression depth in the three hypogravity environments. Depth of compression, however, was inadequate in the female group during Lunar and Martian gravitational environments as compared to 1G (figure 6, Table 4). During hypogravity simulation there was a significant difference in all groups at all hypogravity values in elbow flexion (Tables 3 and 4).

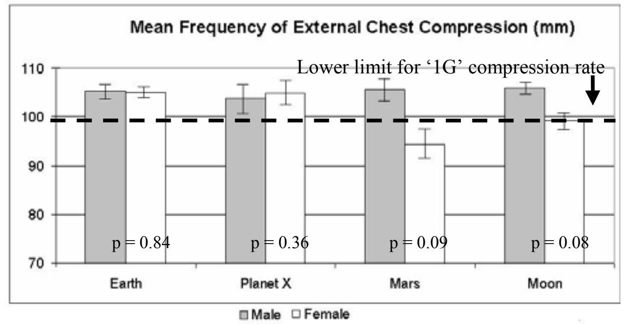

Figure 5: Chest compression frequency in four gravitational environments. Values along y axis represent compression rate (compressions/minute).

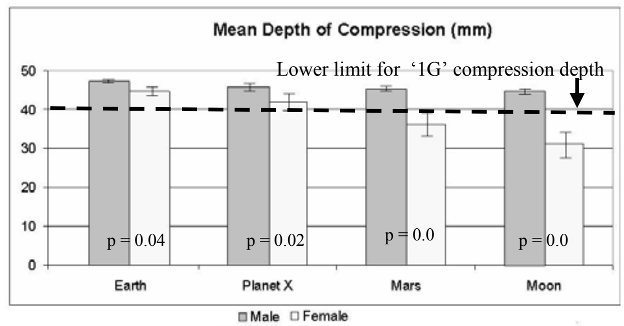

Figure 6: Chest compression depth in four gravitational environments. Values along Y axis represent chest compression depth in millimetres.

Table 3. p Values for Male Results.

Male	p values					
	1G x Px	1G x Ma	1G x Mo	Px x Ma	Ma x Mo	Px x Mo
Mean DCC (mm)	0.119	0.101	0.087	0.274	0.089	0.103
Mean FCC (crp/min)	0.136	0.189	0.196	0.248	0.461	0.187
Elbow Flexion(º)	0.178	0.001	0.000	0.000	0.032	0.000
Load Variation (Kg)	-	-	-	0.003	0.063	0.000
HR Variation (bpm)	0.018	0.002	0.009	0.079	0.449	0.195

DCC: depth of chest compression. FCC: Frequency of chest compression. HR: heart rate. Px: Planet X. Ma: Mars. Mo: Moon.

Table 4. p Values for Female Results

Female	p values					
	1G x Px	1G x Ma	1G x Mo	Px x Ma	Ma x Mo	Px x Mo
Mean DCC (mm)	0.095	0.018	0.000	0.016	0.015	0.001
Mean FCC (crp/min)	0.160	0.053	0.089	0.076	0.243	0.049
Elbow Flexion (º)	0.063	0.005	0.002	0.004	0.297	0.005
Load Variation (Kg)	-	-	-	0.000	0.051	0.000
HR Variation (bpm)	0.000	0.000	0.000	0.420	0.135	0.177

DCC: depth of chest compression. FCC: Frequency of chest compression. HR: heart rate. Px: planet X. Ma: Mars. Mo: Moon.

V. DISCUSSION

The body suspension device successfully reduced subject body weight to values close to that expected to be encountered in hypogravity environments such as those of the Moon and Mars. Subjects were able to monitor their depth and rate of chest compressions effectively, a point highlighted by the fact that mean rates of compression were maintained during all conditions with only one exception.

The results obtained from this unique apparatus and associated systems clearly show that appropriate depths and rates of chest compression do appear to be possible for stronger/heavier (in this case, male) rescuers when subjected to hypogravity in the region of 0.17 to 0.7 Gz. Light weight subjects (predominantly female), however, were unable to achieve adequate chest compression depth in the Lunar and Martian hypogravity environments.

This study suggests that effort required to perform adequate external chest compressions is greater, as demonstrated by the increase in heart rate following 3 minutes of CPR. Furthermore, the angle of elbow flexion increases with reductions in hypogravity suggesting that chest compression force increasingly comes from the arm/shoulder musculature as body weight is reduced. Upper arm strength may therefore be important in achieving adequate external chest compressions in hypogravity.

VI. CONCLUSION

The PUCRS Microgravity Laboratory body suspension system can reproduce hypogravity conditions such as those expected to be experienced on Mars and the Moon. The results of this study of terrestrial CPR in hypogravity suggest that these conditions lead to an alteration of the manner in which the terrestrial method of external chest compression is performed. It appears that the rescuer arm and shoulder muscular effort by means of greater elbow flexion and extension is increased to counter the decrease in body weight. The study also indicates, however, that smaller, weaker rescuers, in this case the female subject group, may not be able to apply sufficient elbow extension force to achieve adequate chest compression under these conditions.

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