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A new method for the performance of external chest compressions during hypogravity simulation

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ABSTRACT

Introduction: 2015 UK resuscitation guidelines aim for 50–60 mm depth when giving external chest compressions (ECCs). This is achievable in hypogravity if the rescuer flexes and extends their arms during CPR, or using a new method trialed; the 'Mackaill–Russomano' (MR CPR) method.

Methods: 10 participants performed 3 sets of 30 ECCs in accordance with 2015 guidelines. A control was used at 1Gz, with eight further conditions using Mars and Moon simulations, with and without braces in the terrestrial position and using the MR CPR method. The MR CPR method involved straddling the mannequin, using its legs for stabilization. A body suspension device, with counterweights, simulated hypogravity environments. ECC depth, rate, angle of arm flexion and heart rate (HR) were measured.

Results: Participants completed all conditions, and ECC rate was achieved throughout. Mean (± SD) ECC depth using the MR CPR method at 0.38Gz was 54.1 ± 0.55 mm with braces; 50.5 ± 1.7 mm without. ECCs were below 50 mm at 0.17Gz using the MR CPR method (47.5 ± 1.47 mm with braces; 47.4 ± 0.87 mm without). In the terrestrial position, ECCs were more effective without braces (49.4 ± 0.26 mm at 0.38Gz; 43.9 ± 0.87 mm at 0.17Gz) than with braces (48.5 ± 0.28 mm at 0.38Gz; 42.4 ± 0.3 mm at 0.17Gz). Flexion increased from approximately 2° - 8° with and without braces respectively. HR did not change significantly from control.

Discussion: 2015 guidelines were achieved using the MR CPR method at 0.38Gz, with no significant difference with and without braces. Participants were closer to achieving the required ECC depth in the terrestrial position without braces. ECC depth was not achieved at 0.17Gz, due to a greater reduction in effective body weight.

1. Introduction

Cardiopulmonary resuscitation (CPR) is a method used in cardiac arrest situations to maintain perfusion to vital organs, with an aim of achieving the return of spontaneous circulation (ROSC). It is a technique developed in the 1960's (Kouwenhoven et al., 1960) and has been refined many times, with evidence-based research ever since (Baskett, 2001). CPR is a skill that is taught to healthcare professionals as well as laypersons worldwide, and the guidelines regarding its delivery are updated every 5 years by international committees (Resuscitation Council (UK) 2017). CPR is critical to maintain a constant blood flow in these situations, to avoid ischemia of these organs and ultimately the death of the casualty. However, the quality of CPR delivered by the rescuer is a crucial factor in whether or not resuscitation is successful, and has several components (Rajab et al., 2011).

The most recent guidelines published in 2015 by the UK Resuscitation Council state that four main criteria contribute to the successful delivery of CPR (Resuscitation Council (UK) 2017). These criteria refer to the depth of external chest compressions (ECCs) (Vadeboncoeur et al., 2014), the rate at which these ECCs are performed (Idris et al., 2015), how much the chest recoils after each ECC (Niles et al., 2011) and the degree to which the CPR is uninterrupted throughout (Perkins et al., 2015). Delivering CPR which meets these four criteria is essential in order to achieve the ROSC, perfuse vital organs and successfully resuscitate the subject.

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Traditionally, 'out of hospital' CPR is delivered with the rescuer kneeling by the side of the subject, as this allows ECCs to be delivered with movement between ECCs and ventilations with minimal interruptions. Evidence shows, particularly in 'out of hospital' cardiac arrests (Dalmarco et al., 2006), that continuous compressions are of greater benefit to minimize interruptions in the less trained (Johnson et al., 1975, Vaillancourt et al., 2011). CPR performed by straddling the subject may be considered when two providers are available or when it is not possible to perform ECCs from the side. This can occur in confined spaces or on a stretcher, with the other provider giving ventilations overhead (Rajab et al., 2011).

A study by Nasiri et al (2014) compared the kneeling, or terrestrial, position with the straddling position whilst giving bag valve mask ventilations to mannequins, and found that performing CPR in the straddling position led to increased ECC and ventilation rates with better quality of resuscitation overall, with regards to the guidelines at the time of the study (Nasiri and Nasiri, 2014). A review by Davey (2014) also found that in simulated conditions, CPR performed in the straddling position resulted in CPR quality similar to that kneeling by the side of the subject (Davey et al., 2014). This evidence suggested that a single rescuer may prefer to perform CPR in the straddling position if performing CPR alone, particularly if they are using a bag valve mask.

Another study by Lei et al (2010) evaluated the efficacy of ECCs delivered using the straddle position and also found this method of CPR to be as effective as the terrestrial position, with rescuers kneeling by the side (Lei et al., 2010). From this, we can assume that in certain situations CPR can be performed in the straddling position, with no detrimental effect on the quality of CPR delivered to the subject. In the terrestrial setting, the evidence from the 2015 UK resuscitation council guidelines show that effective, quality CPR can be delivered to patients at 1Gz (Resuscitation Council (UK) 2017). CPR in a simulated hypogravity environment has demonstrated difficulty in achieving the 2015 guidelines for adequate depth and rate of ECCs (Baers et al., 2016, Dalmarco et al., 2006). A study by Baers et al (2016) found that a reduction in weight due to the simulated hypogravity conditions limited free acceleration of the rescuer's chest, and therefore the amount of force that could be generated, which affected the rescuer's ability to reach the required depth as set out by the 2015 guidelines (Baers et al., 2016). This reduction in weight and limited free acceleration can make ECCs more fatiguing, which will rapidly affect the depth, rate and potentially the quality of ECCs in hypogravity environments, where the rescuer's overall body weight will be reduced. The reduction in quality of ECCs will reduce organ perfusion and decrease the chance of achieving a ROSC (Lurie et al., 2016).

Previous studies have shown, using the older guidelines, that in hypogravity there is a natural flexion of the upper limbs to compensate for this effective reduction in body weight and aid in the generation of force (Dalmarco et al., 2006). These studies have shown arm flexion angles up to 16° compared to 1 - 2° in terrestrial CPR at 1Gz (Dalmarco et al., 2006). Other studies into hypogravity CPR have also found this (Rehnberg et al., 2014, Russomano et al., 2013). They suggest that flexing the arms is a countermeasure needed due to the reduced ability to accelerate the chest and is a way to overcome these difficulties. These studies also suggest that the weight of the rescuer may be a predictor of depth for simulated hypogravity environments (Baers et al., 2016).

However, this adaptation does not address the problem of stability when performing ECCs in the terrestrial position in simulated hypogravity environments. Anecdotally, rescuers in hypogravity simulation felt their knees and legs lifting off the ground with each chest compression, which can interfere with the delivery of effective CPR. Baers et al (2016) also suggested that some rescuers may require an alternative CPR technique to overcome their lower bodyweight and muscle mass to ensure that they can perform adequate ECCs in accordance with the current CPR Guidelines (Baers et al., 2016).

To address these issues, a new method called the 'Mackaill–Russomano' (MR CPR) method was developed to be used in a hypogravity environment or its simulations. This method is similar to the terrestrial straddling position (Lei et al., 2010), with the aim of stabilizing the rescuer whilst delivering ECCs by tucking their heels and lower legs underneath the subject's legs.

The landscape of space flight is currently in a state of change. There is an increase in private companies investing in sub-orbital flights and plans for longer duration missions by space agencies. To date, no astronaut has suffered a cardiac arrest requiring CPR, but there have been several minor cardiac events that have self resolved (Rowe, 1998, Johnson et al., 1975).

There is a possible increased cardiovascular risk in greater microgravity exposure, due to its known deconditioning effects (Baker et al., 2008, Trappe et al., 2009), and less strict screening criteria in laypersons being exposed to microgravity with these cultural changes. Both of these could possibly lead to an increased incidence of cardiovascular events in microgravity or space flight (Johnston et al., 2000). Despite the remote possibility of a serious cardiac event in these scenarios, it is still possible and needs to be prepared for. The prospect of Exploration Class Missions, increased mission duration, and other inherent risks and stresses of space flight, make the likelihood of a serious cardiac event a real risk that needs robust evidence-based protocols.

The aim of this study was to determine the efficacy of the MR CPR method in delivering CPR in simulated hypogravity, both in simulated Moon and Mars gravitational environments, to see if this method was able to achieve the 2015 UK Resuscitation Council guidelines (Resuscitation Council (UK) 2017). As well as this, the study aimed to compare the efficacy of the MR CPR method to terrestrial CPR in 1Gz, simulated Moon and Mars environments, using braces to restrict arm flexion and without them to determine if this influenced the quality of the CPR delivered.

2. Methods

2.1. Participants

Ten healthy volunteers participated in this study (Table 1). The study was conducted at the Microgravity Centre, Pontifícia Universidade do Rio Grande do Sul (PUCRS), Brazil, where the protocol was approved by the PUCRS Ethics and Research Committees. The participants provided a signed a consent form prior to the beginning of the study.

2.2. Equipment

A standard CPR mannequin (Resusci Anne Skill Reporter, Laerdal Medical Ltd., Orpington, UK) was modified to include a linear displacement transducer capable of measuring ECC depth and rate. Real-time feedback of each ECC was provided via a modified electronic guiding system with a light-emitting diode (LED) display to represent the 2015 guidelines in terms of rate and depth. The LED display consisted of a series of colored lights that indicated depth of ECCs (red, 0 - 39 mm; yellow, 40 - 49 mm; green, 50 - 60 mm). An ECC rate of 100 compressions/min^{-1} was set using an electronic metronome. A 6 s interval between each ECC set represented the time taken for two

Table 1
Demographic data of participants in this study (mean ± SD); n = 10.

Age	24.5 ± 2.8
Height (m)	1.75 ± 0.08
BMI (kg/m^2)	24.2 ± 2.4
Weight (kg)	
- Terrestrial (+ 1Gz)	74.2 ± 11.1
- Mars (+ 0.38Gz)	39.5 ± 5.6
- Moon (+ 0.17Gz)	30.1 ± 4.2