Journal of Exercise Physiologyonline

April 2016
Volume 19 Number 2

Official Research Journal of
the American Society of
Exercise Physiologists

ISSN 1097-9751

JEPonline

Is Weight a Pivotal Factor for the Performance of External Chest Compressions on Earth and in Space

Justin Baers[1], Rochelle Velho[1], Alexandra Ashcroft[1], Lucas Rehnberg[1], Rafael Baptista[1], Thais Russomano[1,2]

[1]Microgravity Center, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil, [2]Center of Human and Aerospace Physiological Sciences, School of Biomedical Sciences, Kings College London, London, United Kingdom

ABSTRACT

Baers J, Velho, R, Ashcroft, A, Rehnberg L, Baptista R, Russomano T. Is Weight a Pivotal Factor for the Performance of External Chest Compressions on Earth and in Space? **JEPonline** 2016;19(2):1-16. The purpose of this study was to evaluate the role of body weight in the effectiveness of performing 4 sets of 30 external chest compressions (ECCs) over 1.5 min in accordance with the 2010 Cardiopulmonary Resuscitation (CPR) Guidelines, considering gender differences on Earth and a simulation of the hypogravity of Mars. Thirty males and 30 females performed 4 sets of 30 ECCs with a 6-sec interval between sets to allow for ventilation on a CPR mannequin. The heart rate (HR), pneumotachograph readings (V_E, VO_2 peak), and the rate of perceived exertion (RPE) were measured pre- and post-CPR. The same 30 male volunteers also performed in an additional condition of 0.38 Gz, using the 2010 CPR Guidelines. According to the 2005 CPR Guidelines, set ECC rate and depth were achieved for both genders, and female weight was a strong predictor of true depth, which was below the 2010 CPR Guidelines for the last two ECC sets. VO_2 peak showed no inter-guideline difference, but was greater in the females (18.0 ± 6.5 mL·kg^{-1}·min^{-1}) than in the males (15.6 ± 4.8 mL·kg^{-1}·min^{-1}). Expired ventilation (V_E) was greater for 2010 CPR Guidelines (27.4 ± 7.5 L·min^{-1}) compared to 2005 CPR Guidelines (23.1 ± 6.2 L·min^{-1}) with no gender differences.

Key Words: Basic Life Support, Cardiopulmonary Resuscitation, External Chest Compression

INTRODUCTION

High-quality cardiopulmonary resuscitation (CPR) can optimize patient morbidity and mortality outcomes. This is especially paramount for out-of-hospital cardiac arrests where survival rates are highly variable and often less than 8% (20).

The 2005 CPR Guidelines emphasized the importance of high-quality external chest compressions (ECCs) with an adequate rate and depth that allowed for complete chest recoil post-individual compression while minimizing interruptions (2). Although the 2005 ECC Guidelines were associated with greater patient survival, International Liaison Committee on Resuscitation (12) derived the 2010 ECC Guidelines to further optimize CPR quality. The 2010 algorithm placed more emphasis on ECCs than ventilation with changes to the Basic Life Support (BLS) sequence and the recommended depth.

Effective ECCs constitutes a core component of CPR that must be continued until Advanced Life Support (ALS) can commence to maintain adequate perfusion to the vital organs. In fact, it is especially important if ALS cannot be quickly deployed since it has been shown to decrease the risk of cerebral damage while optimizing survival (11). The 2010 Guidelines (14) indicate that it is essential to perform ECCs to a depth equivalent to at least one-third the anterior-posterior diameter of the chest, which is greater than 50 mm in adults (whereas the 2005 Guidelines recommended 40 to 50 mm depth). The correlation between ECC depth and survival to hospital admission with an adjusted 5% increase in survival odds per 1 mm of ECC depth has been noted (9), although optimal ECCs provide about a one-third of a normal cardiac output (17).

The quality of CPR provided by healthcare providers and laypeople in both in-hospital and out-of-hospital settings has been shown to be suboptimal. Previous work has shown that CPR quality is not influenced by female age when using 2005 Guidelines (24). However, the application of increased ECC depth may be difficult for lightweight or older female rescuers, since an increased difficulty to obtain adequate ECCs during reduced gravitational simulations has been demonstrated (23).

Research into the effectiveness of CPR in altered gravitational fields has demonstrated that the quality of CPR in ground-based simulated Mars hypogravity (0.38Gz) is adequate with the current guidelines (6,23), but shows that the traditional CPR technique is different to remain effective. Yet, little is about the current ECC quality due the rescuer characteristics. Previous work has suggested that CPR quality is influenced by weight and height when using the 2005 Guidelines (6).

The application of increased ECC depth may be difficult for lightweight rescuers. It may also require adaptations of the current guidelines, especially in conditions of hypogravity (15,19). Thus, the purpose of this study was to determine if there were any gender differences in the effectiveness of performing 4 sets of ECCs over 1.5 min. To further determine if weight is a pivotal factor in ECC effectiveness, the performance of the ECCs was carried out in a simulated hypogravity (0.38Gz) environment. In addition to assessing the quality of the ECCs, this study also evaluated the relationship between the rescuer height and weight and oxygen consumption between genders and BLS conditions.

METHODS

Subjects

This was a trial that involved volunteers of both genders performing CPR in accordance to the 2005 and the 2010 CPR Guidelines. There was an additional condition for men, where they performed CPR in accordance with the 2010 CPR Guidelines in hypogravity, specifically 0.38Gz (simulating Martian gravitational field), to determine if their weight was a factor in the quality of ECCs. Ethical approval was obtained from the Pontifical Catholic University of Rio Grande do Sul, Brazil. Healthy male (22.5 ± 3.5 yr) and female (21.6 ± 3.5 yr) subjects were recruited, familiarized with the equipment, and had to demonstrate an adequate CPR technique prior to commencing the study.

Procedures

Following the measurement of the subjects' height and weight, body mass index (BMI; $kg \cdot m^{-2}$) was calculated. Baseline variables were recorded for 5 min prior to BLS, including minute ventilation (V_E), oxygen consumption (VO_2), and heart rate (HR). An Aerosport VO2000 analyzer (MedGraphics, Saint Paul, MN, USA) recorded V_E and VO_2. The analyzer was auto-calibrated prior to each protocol. The subjects' VO_2 was standardized, calculated, and recorded directly by a computerized ergospirometric system (Aerograph 4.3, AeroSport Inc., Ann Arbor, MI, USA). Heart rate was measured using an Onyx 9500 fingertip pulse oximeter (Nonin Medical Inc., Plymouth, MN, USA).

Volunteers performed 4 sets of ECCs for 1.5 min using both the 2005 and the 2010 CPR Guidelines. A minimum of 10 min rest was given between performances and the order of ECC guidelines was randomized. The ECC depth and rate were measured using a CPR mannequin (Resusci Anne Skill Reporter, Laerdal Medical Ltd., Orpington, UK) at 1Gz and during 0.38Gz simulation. Audio and visual real-time feedback of ECCs were provided to the subjects via an electronic metronome (100 $beats \cdot min^{-1}$) and a series of light-emitting diodes (LED) that indicated depth of ECCs (red, 0–39 mm; yellow, 40–49 mm; green, 50–60 mm). A 6-sec interval between each ECC set represented the time taken for 2 ventilations. A DataQ acquisition device (DATA-Q Instruments Inc., Akron, OH, USA) and WinDaq data acquisition software enabled data collection from the mannequin.

The subjects' HR was recorded before and immediately after the completion of each protocol. After 4 sets of ECCs, the subjects' perceived exertion was determined using the Borg scale (5). The mannequin's chest system was calibrated between volunteers using inputs of 0 and 60 mm.

To study the condition of hypogravity, the men performed an additional set using a custom-built body suspension device (BSD) to simulate 0.38Gz. The device is pyramidal in shape and consists of carbon steel bars of 6 cm × 3 cm thickness (base area, 300 cm × 226 cm; height, 200 cm). It consists of a body harness and counterweight system of 20 bars of 5 kg each (Figure 1), which was made by the Microgravity Centre, PUCRS (REF).

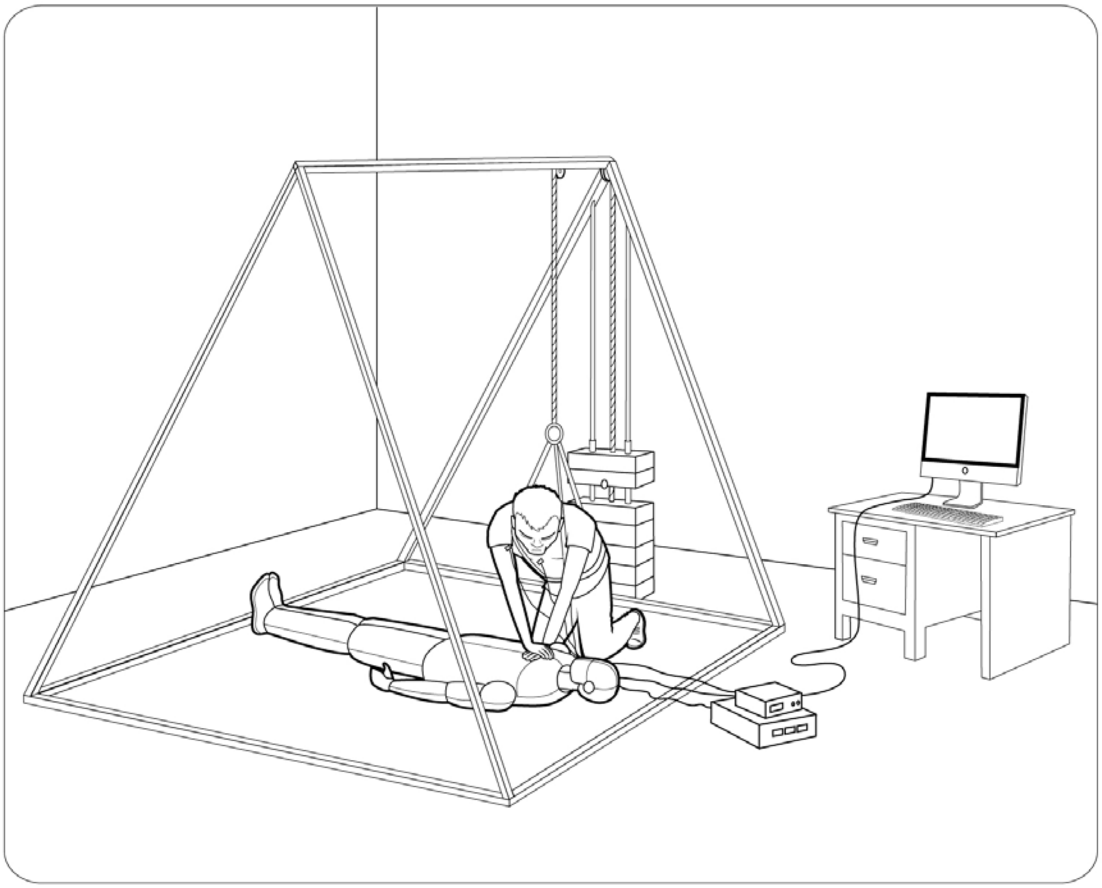

Figure 1. Male Volunteer Performing External Chest Compression Wearing a Body Harness for Hypogravity Simulation.

A steel cable connected the counterweights through a pulley system to the harness worn by the volunteer. The necessary counterweights were calculated using the following Equations:

$$RM = (0.6\ BM \times SGF) / +1G \quad (1) \text{ (Equation 1)}$$

$$CW = 0.6\ BM - RM \quad (2) \text{ (Equation 2)}$$

where RM is the relative mass (in kg), 0.6 BM is the percentage of total body mass, SGF is the simulated gravitational force ($m{\cdot}s^{-2}$), +1G = 9.81 $m{\cdot}s^{-2}$ and CW is the counterweight (in kg).

During the performance of ECCs, the mannequin was placed supine on the floor with the subject adopting the terrestrial CPR position. Measurement of the physiological variables remained the same as for the previous protocol.

Statistical Analyses

Data of physiological variables was determined by either averaging the last 30 sec of exercise or comparing the last 30 sec of exercise to the baseline state. Percentage of maximum HR was calculated by comparing post-ECC HR with maximum HR, which was calculated using the 220-age equation (22). VO_2 peak represents the highest recorded VO_2 during the 4 ECC sets. The ECC depth and rate were reported as mean values (±SD). The ECC depth was analyzed as maximum depth (D_{Max}) achieved and true depth (D_T), which was calculated by subtracting the depth of inadequate recoil ($D_{IRecoil}$), the distance not compressed between subsequent ECCs, from D_{Max} (23).

The measures were derived *post hoc* from the data files using GraphPad Prism v5.0a for analysis. Statistical comparisons were performed using a one-way, non-parametric ANOVA test and on ECCs using a two-way ANOVA. A 95% confidence interval calculation around the mean was used. The level of significance was set as $P \leq 0.05$.

In the hypogravity study, the Pearson product moment correlation was used to determine the relationship between ECC rate and depth. Multivariate linear regression was utilized to determine the predictors of ECC depth and VO_2. All variables with $P \leq 0.1$ were included in the model.

RESULTS

Sixty subjects were recruited for this study (Table 1).

Table 1. Descriptive Data of the Subjects.

Male (n=30)		**Female** (n=30)	
Age (yrs)	22.5 ± 3.5	**Age** (yrs)	21.6 ± 3.5
Age (range)	17-30	**Age** (range)	17-32
Weight (kg)	78.2 ± 13.1	**Weight** (kg)	61.9 ± 10.3
Height (m)	1.80 ± 0.07	**Height** (m)	1.65 ± 0.07
BMI ($kg \cdot m^{-2}$)	23.3 ± 2.9	**BMI** ($kg \cdot m^{-2}$)	22.5 ± 2.6

Although the subjects were matched for age, the female subjects weighed less ($P<0.0001$), were shorter in height ($P<0.0001$), and had a smaller BMI ($P<0.05$) compared to their male counterpart. The mean ± SD D_{Max} of the 4 sets for male and female volunteers for 2005 and 2010 ECC Guidelines are presented in Figure 2. All male volunteers were able to abide by the 2005 [47.1 ± 3.0 mm] and 2010 [57.0 ± 2.3 mm] ECC guidelines for depth. Female volunteers were able to abide by the 2005 ECC Guidelines [45.0 ± 3.6 mm], but considerable variation in the range of ECC D_{Max} was seen using the 2010 ECC Guidelines, despite mean D_{Max} being above the effective limit [51.6 ± 4.3 mm; Figures 2A and 2B]. D_{Max} for female volunteers was less than that achieved by male volunteers when using the 2010 ECC Guidelines (Figure 2B). However, not all volunteers allowed full recoil of the mannequin's chest. For the 2005 ECC Guidelines, $D_{IRecoil}$ was less for the female subjects [3.1 ± 3.6 mm] than male volunteers [6.7 ± 4.9 mm; Figure 2A]. No difference was noted in $D_{IRecoil}$ for the 2010 ECC Guidelines when the females [3.2 ± 4.3 mm] were compared to the males [4.6 ± 3.5 mm]. Moreover, multivariate regression analysis was performed to determine the predictors of D_{Max}. For the 2005 ECC Guidelines, only female weight ($r=0.49$, $P=0.006$) and BMI ($r=0.47$, $P=0.008$) were strong predictors of D_{Max}. Female weight ($r=0.56$, $P=0.001$) and BMI ($r=0.46$, $P=0.01$) showed a greater positive correlation compared to male weight ($r=0.38$, $P=0.04$) and BMI ($r=0.39$, $P=0.03$) using the 2010 ECC Guidelines (Figure 2D).

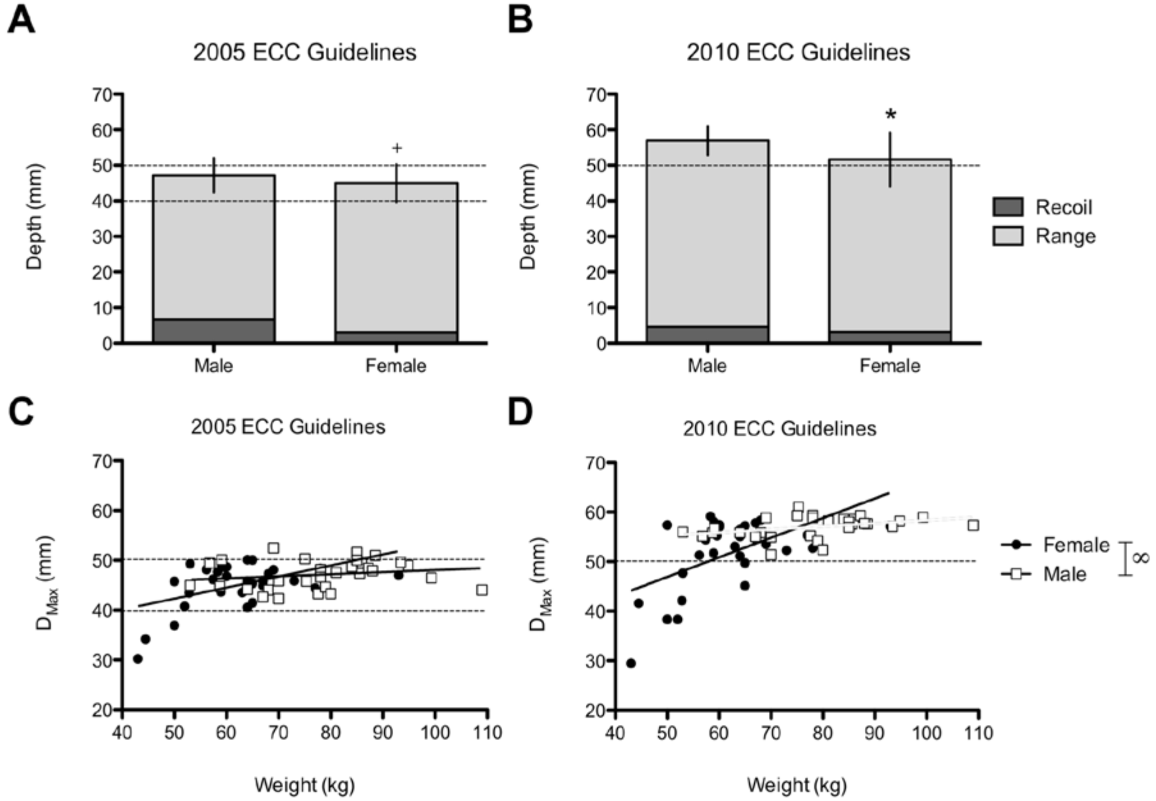

Figure 2. Male and Female Mean ± SD Maximum Depth (D_{Max}) with Depth of Compressed Chest Post-Inadequate Recoil ($D_{IRecoil}$) for All Four ECC Sets and Correlation of Body Weight and D_{Max} Among Males and Females. Figures 2A & 2C, the 2005 ECC Guidelines and Figures 2B & 2D, the 2010 ECC Guidelines. The dashed lines depict the effective limit(s) of depth for each respective guideline. n=60; *Significant difference in maximum depth, $P<0.05$. +Significant difference in recoil, $P<0.05$. ∞Significant difference in gender, $P<0.05$.

The male and female subjects' mean ± SD for true depth (D_T) of individual ECC sets, as calculated from $D_{IRecoil}$ to D_{Max}, was within the effective limits set by the 2005 ECC Guidelines for both the male and female subjects. The male mean ± SD D_T values for ECC sets 1, 2, 3, and 4 were 40.9 ± 5.0 mm, 40.4 ± 5.0 mm, 40.6 ± 4.9 mm and 40.1 ± 4.6 mm while the female mean D_T values were 42.2 ± 5.5 mm, 42.0 ± 5.5 mm, 41.7 ± 5.0 mm, and 41.2 ± 5.5 mm, respectively. Mean ± SD D_T for male volunteers were above the effective limit set by the 2010 ECC Guidelines for all four ECC sets [52.4 ± 4.2 mm, 52.1 ± 4.6 mm, 52.5 ± 3.5 mm, and 52.6 ± 3.9 mm]. For female volunteers using the 2010 ECC Guidelines, mean ± SD D_T for ECC sets 1, 2, 3, and 4 were 48.8 ± 7.5 mm, 48.4 ± 7.7 mm, 48.3 ± 7.1 mm, and 48.4 ± 8.0 mm, respectively. No difference in mean ± SD D_T was observed between genders when using the 2005 ECC Guidelines. However, the mean ± SD D_T for the last two ECC sets were greater for the male subjects using the 2010 ECC Guidelines ($P<0.05$). Moreover, multivariate regression analysis showed no predictors of D_T for either gender using the 2005 ECC Guidelines. Only female weight ($r=0.38$, $P=0.04$) was a strong predictor of D_T using 2010 ECC Guidelines. The mean ± SD ECC rates for both male and female subjects were successfully maintained above 100 compressions·min^{-1} for each set for both the 2005 and the 2010 ECC Guidelines (Table 2).

Table 2. Male and Female Mean ± SD Rate of Individual ECC Sets.

ECC Guidelines	Gender	Rates for Individual ECC Sets, Compressions·min^{-1}			
		1	2	3	4
2005	Female (n = 30)	105 ± 9	105 ± 8	105 ± 7	106 ± 7
	Male (n = 30)	104 ± 5	105 ± 5	105 ± 6	105 ± 5
2010	Female (n = 30)	106 ± 7	105 ± 7	105 ± 7	104 ± 6
	Male (n = 30)	105 ± 4	104 ± 4	104 ± 3	104 ± 3
2010 at 0.38G$_z$	Male (n = 30)*	103 ± 6*	103 ± 5*	103 ± 5*	103 ± 5*

* In hypogravity condition only males were invited to perform an extra set of ECCs

The mean ± SD male and female rescuer HR at baseline, post-ECC, as well as percent change and percent of maximum HR are illustrated in Table 3. No difference in baseline HR was observed between male and female subjects. HR was higher for both genders when the 2010 ECC Guidelines were used. When genders were compared in accordance to either ECC Guidelines, HR responses were greater for female subjects than male subjects.

Table 3. Mean ± SD Male and Female Heart Rate Responses between Guidelines.

Mean ± SD (beats·min^{-1})				Gender
Baseline	**Heart Rate**	**2005 Guidelines**	**2010 Guidelines**	
84 ± 15	**HR post-ECC**	111 ± 19	117 ± 21^{+}	Male
	%Δ	33.8 ± 18.4	41.4 ± 22.8^{+}	
	%Max	56.1 ± 9.4	59.2 ± 10.9^{+}	
88 ± 13	**HR post-ECC**	129 ± 17**	138 ± 20$^{**/+}$	Female
	%Δ	48.9 ± 25.1*	59.4 ± 27.4$^{*/+}$	
	%Max	65.1 ± 8.7**	69.7 ± 9.8$^{**/+}$	

HR responses are depicted as baseline and post-ECC values (beats·min^{-1}), percent change from baseline and percent of maximum heart rate (maximum heart rate calculated using 220-age). n=60; Significant difference between gender: *P<0.05, **P<0.0001; +Significant difference between ECC guidelines, P<0.05.

Mean ± SD male and female rescuer V_E increased from 11.4 ± 5.9 $L \cdot min^{-1}$ and 10.2 ± 4.7 $L \cdot min^{-1}$ at rest to 23.9 ± 6.1 and 22.2 ± 6.2 $L \cdot min^{-1}$ for 2005 ECC Guidelines and 27.5 ± 7.8 and 27.3 ± 7.1 $L \cdot min^{-1}$ for the 2010 ECC Guidelines, respectively. With respect to gender, there was no significant difference in the increase in V_E from rest for either of the ECC Guidelines (Figure 3A).

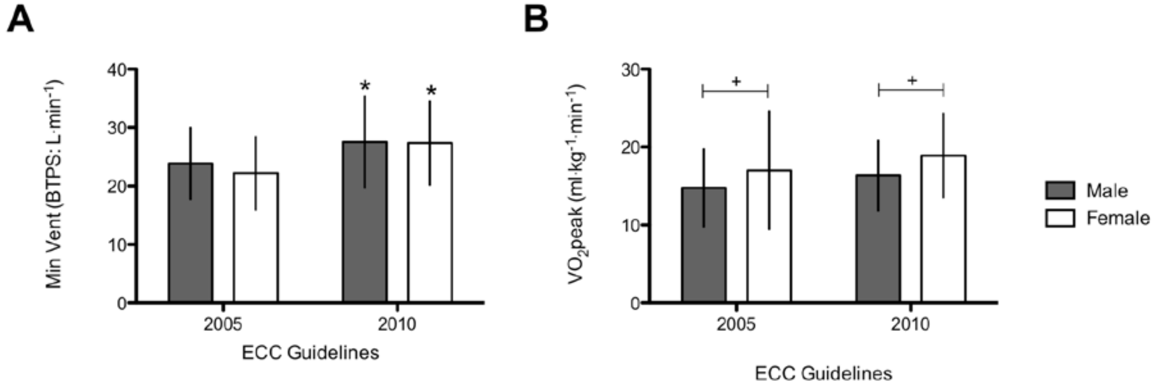

Figure 3. Male and Female Minute Ventilation (V_E) and Peak Oxygen Consumption (VO_2 peak) Normalised to Weight between Guidelines. Baseline V_E for male and female subjects were 11.4 ± 5.9 $L \cdot min^{-1}$ and 10.2 ± 4.7 $L \cdot min^{-1}$, respectively. Baseline VO_2 for male and female subjects was 3.2 ± 1.1 and 4.4 ± 2.4 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively. n=60; *Significant difference between ECC Guidelines, $P<0.05$. +Significant difference between gender, $P<0.05$**.**

During the last 30 sec of the ECCs, V_E increased across both genders from rest by approximately 160% for the 2005 and 210% for the 2010 ECC Guidelines. There was no significant difference between the mean ± SD resting level VO_2 normalized to weight in female volunteers [4.4 ± 2.4 $mL \cdot kg^{-1} \cdot min^{-1}$] when compared to the male subjects [3.2 ± 1.1 $mL \cdot kg^{-1} \cdot min^{-1}$].

As can be seen in Figure 3B, the difference in VO_2 peak between the two Guidelines was not statistically significant, however between genders it was significant in both guidelines, being higher among the female subjects for the 2005 [17.0 ± 7.5 $mL \cdot kg^{-1} \cdot min^{-1}$] and the 2010 ECC Guidelines [18.9 ± 5.4 $mL \cdot kg^{-1} \cdot min^{-1}$] compared with the males [14.8 ± 5.0 $mL \cdot kg^{-1} \cdot min^{-1}$] and [16.4 ± 4.5 $mL \cdot kg^{-1} \cdot min^{-1}$] for the 2005 and the 2010 ECC Guidelines, respectively. During the last 30 sec of the ECCs, VO_2 peak increased from rest by approximately 340% for the female subjects and 350% for the male subjects for either ECC Guideline.

Multivariate regression analysis was also performed to determine the predictors of VO_2. For the 2005 ECC Guidelines, only female weight (r=-0.40, P=0.03) and BMI (r=-0.36, P=0.05) were strong predictors of VO_2. Female weight (r=-0.53, P=0.003) and BMI (r=-0.50, P=0.005) showed a greater negative correlation compared to male weight (r=-0.42, P=0.02) and BMI (r=-0.38, P=0.04) using the 2010 ECC Guidelines (Figures 4B & 4D).

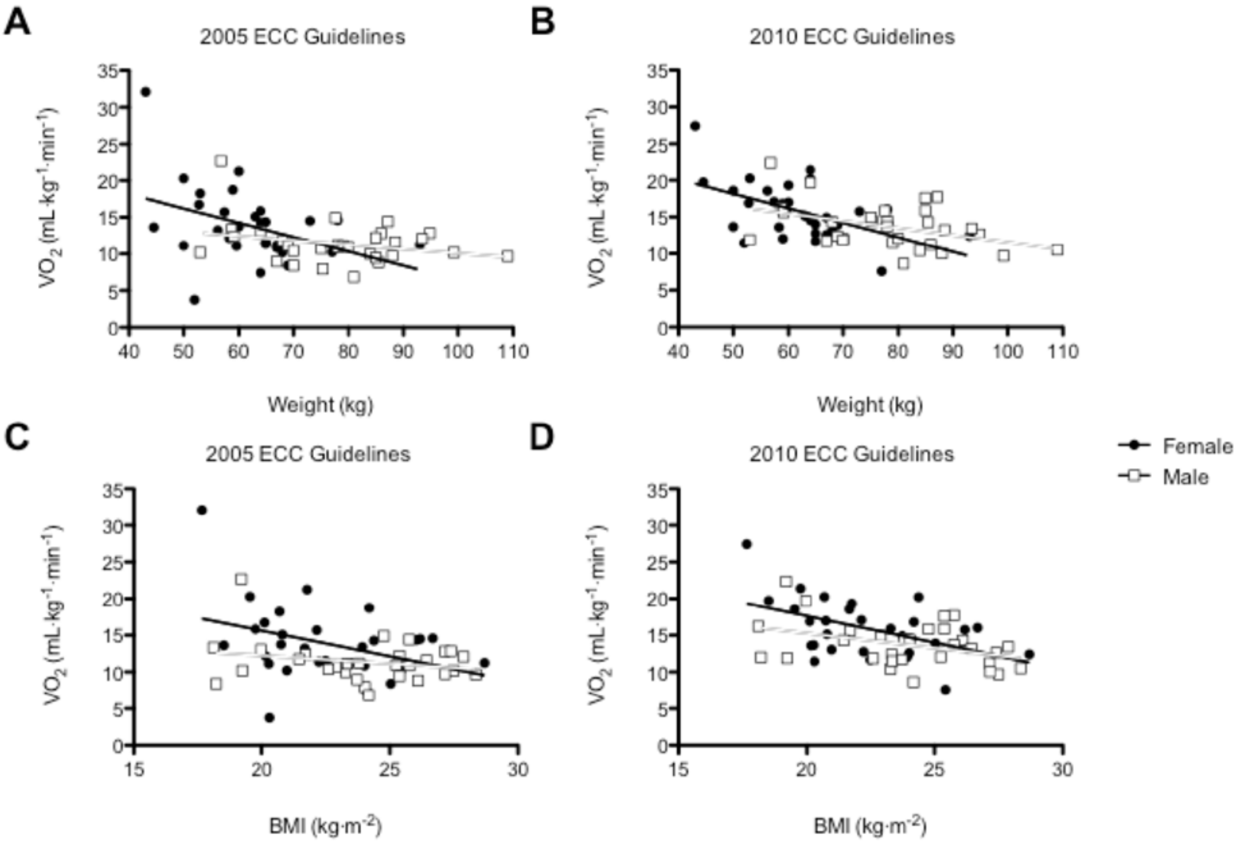

Figure 4. Correlations of VO_2 with Body Weight and BMI among Males and Females. (A & C) 2005 ECC Guidelines and (B & D) 2010 ECC Guidelines (n=60; *P<0.05).

The Borg scale showed that there was an inter-gender and inter-guideline difference in the mean ± SD RPE, with RPE being higher in the females and for the 2010 ECC Guidelines (Figure 5).

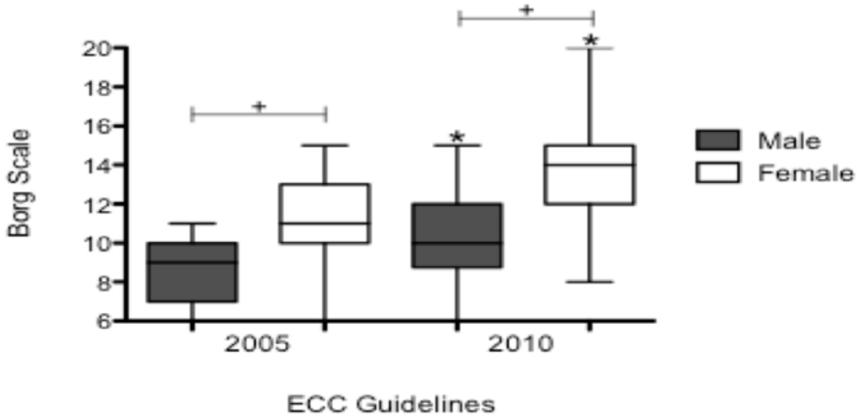

Figure 5. Male and Female Mean ± SD Rate of Perceived Exertion for Four Sets of ECCs between Guidelines. n=60; *Significant difference between ECC Guidelines, P<0.05; +Significant difference between gender, P<0.05.

The results of the study on hypogravity are as follows. The mean D_T and ECC rate were sufficient during using either the 2005 and the 2010 Guidelines at +1Gz [52.3 ± 3.6 mm; 104 ± 3 ECC/min] and simulated 0.38Gz [53.4 ± 4.1 mm; 103 ± 5 ECC/min]. No differences were noted between the two gravitational conditions for these variables. The mean $D_{IRecoil}$ was less during 0.38Gz [1.6 ± 1.8 mm] when compared to +1Gz [4.6 ± 3.5 mm]($P<0.0001$). Throughout the last 30 sec of the ECCs, mean VO_2 increased from 3.2 ± 1.1 mL·kg^{-1}·min^{-1} at rest to greater levels during simulated 0.38Gz [17.9 ± 4.5 mL·kg^{-1}·min^{-1}] compared to +1Gz [13.7 ± 3.1 mL·kg^{-1}·min^{-1}].

Multivariate regression analysis was performed to determine the predictors of D_T, $D_{IRecoil}$, ECC rate, and VO_2 at +1Gz and during simulated 0.38Gz. The regression model variables included height and weight (Table 4). Weight was a strong predictor of D_T during simulated 0.38Gz ($r=0.41$, $P=0.02$), but not at +1Gz ($r=0.12$) (Figure 6A). No variable was a significant predictor of $D_{IRecoil}$ or ECC rate. Weight was, again, a significant predictor of VO_2 during simulated 0.38Gz and, in this case, also at +1Gz ($r= -0.42$, $P=0.02$ for both; Figure 6B).

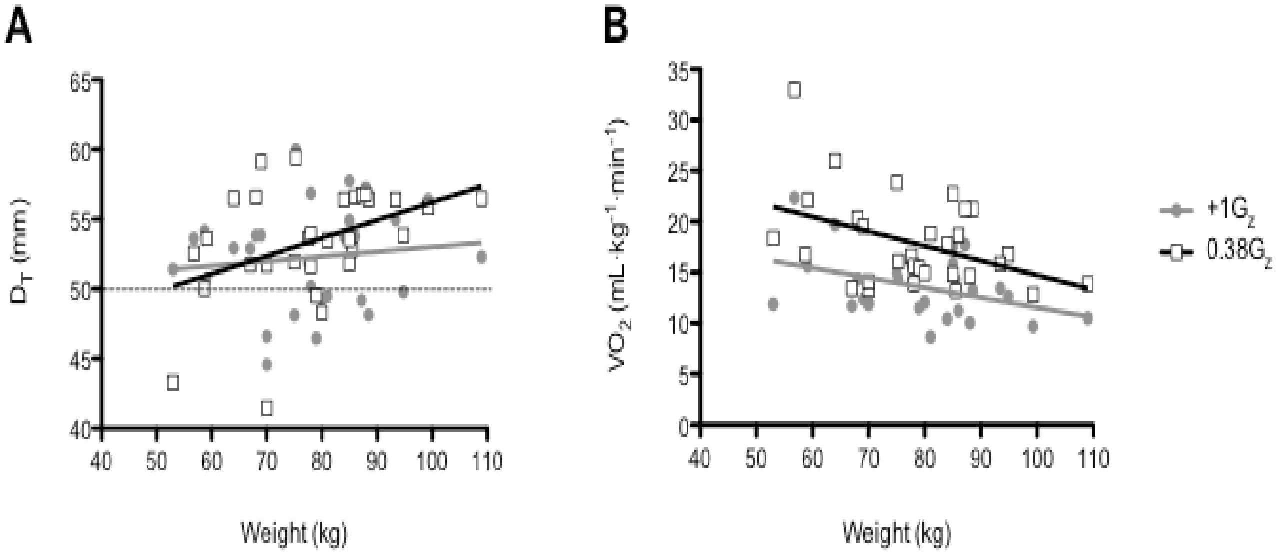

Figure 6. Correlation of Body Weight with D_T and VO_2 at +1Gz and 0.38Gz using the 2010 Guidelines. (A) D_T; the dashed line depicts the effective limit of depth for the 2010 ECC Guidelines. (B) VO_2. n=60.

Table 4. Regression Data for D_T, $D_{IRecoil}$, ECC Rate and VO_2 at +1G_z and 0.38G_z, using the 2010 Guidelines (n=30).

Conditions	D_T		$D_{IRecoil}$		ECC Rate		O_2/kg		VO_2	
	+1G_z	**0.38G_z**	**+1G_z**	**0.38G_z**	**+1G_z**	**0.38G_z**	**+1G_z**	**0.38G_z**	**+1G_z**	**0.38G_z**
Height	r=-0.06	r=0.26	r=0.20	r=-0.01	r=0.05	r=0.27	r=-0.28	r=-0.31	r=0.24	r=0.20
	P=0.75	P=0.16	P=0.30	P=0.97	P=0.79	P=0.15	P=0.13	P=0.09	P=0.20	P=0.30
Weight	r=0.12	r=0.41	r=0.12	r=-0.13	r=0.02	r=0.11	r=-0.42	r=-0.42	r=0.36	r=0.31
	P=0.52	P=0.02	P=0.54	P=0.48	P=0.93	P=0.58	P=0.02	P=0.02	P=0.06	P=0.10
BMI	r=0.19	r=0.40	r=0.05	r=-0.17	r=0.00	r=-0.02	r=-0.38	r=-0.38	r=0.33	r=0.28
	P=0.31	P=0.03	P=0.81	P=0.36	P=0.99	P=0.92	P=0.04	P=0.04	P=0.07	P=0.14

DISCUSSION

The 2005 and the 2010 ECC Guidelines state that effective ECCs is the key component to ensure sufficient hemodynamics from time of arrest to application of ALS. Outcome from cardiac arrest is worsened when CPR quality is suboptimal. The low survival rates in cardiac arrest patients (17% in-hospital; 8% out-of-hospital) post discharge may be attributable to poor CPR (18,20). There are limited studies that have evaluated the influence of gender or hypogravity on the administration of effective 2010 ECC Guidelines.

The mean D_{Max} achieved during the ECCs indicate that the male and female subjects were able to perform to 2005 ECC Guidelines (Figure 2A), which concurs with a 754-volunteer study (19). In the present study, the male and female subjects performed the ECCs to a mean ± SD depth of 43.7 ± 8.1 mm and 40.6 ± 7.9 mm, respectively, and the total percentage of the ECCs performed within the effective limits was similar for both genders (P=0.2). However, a previous study conducted by Peberdy et al. (19) using multivariate regression analysis found gender to be a significant predictor of ECC depth (r=0.13, P=0.001). The males performed the ECCs at greater depth compared to the females (P<0.0001), given that the females were more disposed to perform ECCs of insufficient depth (P=0.0001) while the males had a greater tendency to perform ECC depths greater than 50 mm (P=0.0001). These gender differences were not in agreement with the D_{Max} observed in this study. Interestingly, $D_{IRecoil}$ was smaller for the female subjects abiding by the 2005 ECC Guidelines, despite no difference in D_{Max} (Fig. 2A). This is supported by the positive correlation seen between weight and D_{Max} (r=0.49, P=0.006) in the females using the 2005 ECC Guidelines and their weight (61.9 kg) being lighter in comparison to the males (78.2 kg), which could facilitate ease of chest decompression between ECCs thereby reducing $D_{IRecoil}$ (Figure 2C).

The positive correlation between weight and D_{Max} was also seen in the females using the 2010 ECC Guidelines (r=0.56, P=0.001; Figure 2D). These findings are supported by a recent study that observed females weighting less than 62.7 kg were 4.7 to 6.3 times more likely to produce insufficient ECCs (15). Fifty percent of the female subjects in the present study weighted less than 62.7 kg. In addition, D_{Max} and D_T for the last 2 sets of ECCs [48.3 ± 7.1 mm and 48.4 ± 8.0 mm] were lower for the female subjects compared to the males when using the 2010 ECC Guidelines (Figure 2B), which may be attributable to inter-gender differences in weight, differential muscle mass, and strength (3).

Two main components of high-performance ECC depth at +1Gz are body weight and the free acceleration of the rescuer's upper body towards the mannequin. However, it was noted that the reduction in apparent weight by the harness limited the free acceleration of the rescuer and rendered weight as the only important variable producing ECC depth during simulated 0.38Gz. The positive correlation between D_T and weight (r=0.41, P=0.02; Figure 6A) emphasizes the importance that lightweight rescuers may require strength training and alteration of their CPR technique to conduct effective CPR in hypogravity (21). Previous studies have shown that a natural adaptation to performing CPR in hypogravity is to increase the movement of the upper limb to countermeasure the reduced ability to accelerate the chest (6,21,23), which is contrary to the advice of the guidelines to keep your arms straight and locked. It also confirms the notion that rescuer's weight may be a predictor of depth for simulated reduced gravity environments (6).

These findings, in conjunction with the finding that female weight was also a strong predictor of D_T (r=0.38, P=0.04) using the 2010 ECC Guidelines, reinforce the importance that lightweight rescuers may require strength training and alteration of their CPR technique to conduct effective CPR. The present study demonstrates that the ECC rate did not vary between guidelines or gender (Table 2), which implies that it was not a contributor to the difference in D_{Max}. For both guidelines, the increased HR for female volunteers indicated a greater physical effort compared to the males, and the females achieved a higher percentage of maximum HR post-ECCs despite being matched for age with their male counterparts (Table 3). The gender HR results support those found by previous studies pertaining to the 2005 ECC Guidelines (6,13).

Baseline VO_2 was the only physiological variable that was higher for the females compared to the males. This can be attributed to the female subjects weighting approximately 16 kg less than their male counterparts. Furthermore, it is important to note that VO_2 peak was measured and used as an estimation of VO_2 max (7).

For the 2005 ECC Guidelines, the increase in VO_2 peak for the female subjects corroborates with the inter-gender weight difference and implies that additional work done was required for the females to perform the ECCs equivalent to male rescuers (Figure 3). The negative correlations between VO_2 and female weight (r=-0.40, P=0.03) and BMI (r=-0.36, P=0.05) also indicate lightweight females exert themselves more in order to conduct adequate CPR in comparison to heavier females.

For the 2010 ECC Guidelines, there was no increase in VO_2 peak for the male subjects, given that the males may have compensated by the rise in HR and V_E (Table 3 and Figure 3). Although this trend in VO_2 peak was replicated for the female subjects, their D_T was below the effective limits and lower compared to the males in the last two ECC sets despite a parallel increase in HR and V_E. This indicates that the females may require a greater VO_2 to achieve 2010 Guidelines. Moreover, the finding that both genders showed weight and BMI to be strong predictors of VO_2 highlights an increased effort, especially for lightweight individuals to achieve adequate CPR in accordance with the current ECC Guidelines.

The negative correlations seen between VO_2 and weight (r=-0.42, P=0.02; Figure 6B) also highlight an increased effort, especially for the lightweight males to conduct adequate CPR in accordance with the current ECC Guidelines in simulated 0.38Gz. However, the reduction in upper body weight may facilitate ease of chest decompression between ECCs, which is indicated by a lower mean $D_{IRecoil}$ during simulated 0.38Gz compared to +1Gz.

This study highlights that rescuer gender is of clinical importance when administering effective CPR. It may not be feasible for older females to perform the 2010 ECC Guidelines. In particular, post-menopausal females exhibit a greater loss in bone mineral density, sarcopenia, and VO_2 due to the lack of estrogen when compared to aging men (8). CPR has been shown to elicit ischemic symptoms in rescuers with coronary artery disease, which is a risk that also increases with age (16).

The females' RPE for 4 sets of 30 ECCs was greater than the males' RPE. This finding is consistent with their increase in VO_2 peak (Figure 4). Interestingly, although VO_2 peak did not differ between the Guidelines, both genders at rated current ECC Guidelines as more difficult. This might have been influenced by the fact that the subjects were not blinded to the LED color system used and had a pre-conception that illuminating green LEDs (50-60 mm) for current ECC Guidelines could have been less attainable than yellow LEDs (40-49 mm) for the 2005 ECC Guidelines; all yellow LEDs had to be illuminated in order to achieve current Guidelines.

The results of the present study were obtained using real-time audiovisual feedback during resuscitation. Prior clinical investigations have demonstrated that the use of real-time feedback dramatically improves ECC quality and reduces ECC depth and rate variance (1). This suggests that our results are not applicable to alternate environments that lack feedback and may underestimate actual ECC performance in an emergency.

It is possible that CPR quality was improved in later protocols because of a learning effect. However, a past CPR feedback study noted no difference in subsequent trials conducted when constructive verbal feedback was withheld (10). During this investigation, no constructive verbal feedback was given to volunteers, post-ECC protocol; therefore, it is unlikely that a learning effect had a profound influence.

There may have been confounding factors on the subjects' CPR performance that were not accounted for in this study (e.g., physical characteristics of the rescuer, like lean muscle mass, and prior frequency of exposure to CPR), although it was shown that ECC depth did not differ between the ALS/BLS-certified and the non-certified subjects (P=0.6) (19). An incremental exercise test prior CPR testing would also be ideal. This would allow percentage of VO_2 max to be calculated to determine if this was a factor in performing ECCs (25).

The differences in chest wall compliance between humans and mannequins do not account for variations in body anthropometrics. It may result in a false representation of the compliance, since human's chest generally requires greater force to compresses the same distance on a mannequin (4).

CONCLUSIONS

This study demonstrated that there may be a gender difference in the effectiveness of BLS in the delivering of ECC, using the 2010 Guidelines. The female subjects were more likely to perform inadequate ECCs, as they tended to be shorter, weigh less, and possibly have a smaller muscle mass compared to the males. The present study also showed that the female subjects had a higher physiological demand when performing the ECCs. This finding suggests that these physical parameters made ECCs harder for females to perform. Hypogravity simulation data from the male subjects reduced their effective weight while retaining their intrinsic muscle mass. These data showed that the male subjects were still able to perform adequate ECCs in accordance with the 2010 Guidelines. This indicates that weight is not the only factor in effective ECC. Muscle mass may play an important role that counterbalances low weight situations. Therefore, female rescuers may require additional strength training and alternative CPR techniques to overcome their lower bodyweight and muscle mass to ensure that they can perform adequate ECCs in accordance with the current CPR Guidelines.

Address for correspondence: Rafael Baptista, PhD, Microgravity Centre, Pontifical University of Rio Grande do Sul, Porto Alegre, RS, Brazil, 90619-900, Email: rafael.baptista@pucrs.br

REFERENCES

1. Abella BS, Edelson DP, Kim S, Retzer E, Myklebust H, Barry AM, O'Hearn N, Hoek TLV, Becker, LB. CPR quality improvement during in-hospital cardiac arrest using a real-time audiovisual feedback system. ***Resuscitation.*** 2007;73:54-61.

2. American Heart Association. 2005 American Heart Association (AHA) guidelines for cardiopulmonary resuscitation (CPR) and emergency cardiovascular care (ECC) of pediatric and neonatal patients: Pediatric basic life support. ***Pediatrics.*** 2006;117: e989-1004.

3. Ashton A, McCluskey A, Gwinnutt CL, Keenan AM. Effect of rescuer fatigue on performance of continuous external chest compressions over 3 min. ***Resuscitation.*** 2002;55:151-155.

4. Baubin MA, Gilly H, Posch A, Schinnerl A, Kroesen GA. Compression characteristics of CPR manikins. ***Resuscitation.*** 1995;30:117-126.

5. Borg G. Perceived exertion as an indicator of somatic stress. ***Scand J Rehabil Med.*** 1970;2:92-98.

6. Dalmarco G, Calder A, Falcão F, de Azevedo DF, Sarkar S, Evetts S, Moniz S, Russomano T. Evaluation of external cardiac massage performance during hypogravity simulation. ***Conf Proc IEEE Eng Med Biol Soc.*** 2006;1:2904-2907.

7. Day JR, Rossiter HB, Coats EM, Skasick A, Whipp BJ. The maximally attainable VO_2 during exercise in humans: The peak vs. maximum issue. ***J Appl Physiol.*** 2003;95: 1901-1907.

8. Doherty TJ. The influence of aging and sex on skeletal muscle mass and strength. ***Curr Opin Clin Nutr Metab Care.*** 2001;4:503-508.

9. Edelson DP, Abella BS, Kramer-Johansen J, Wik L, Myklebust H, Barry AM, Merchant, RM, Hoek TL, Steen PA, Becker LB. Effects of compression depth and pre-shock pauses predict defibrillation failure during cardiac arrest. ***Resuscitation.*** 2006;71:137-145.

10. Handley AJ, Handley SAJ. Improving CPR performance using an audible feedback system suitable for incorporation into an automated external defibrillator. ***Resuscitation.*** 2003;57:57-62.

11. Handley AJ, Koster R, Monsieurs K, Perkins GD, Davies S, Bossaert L. European Resuscitation Council guidelines for resuscitation 2005. Section 2. Adult basic life support and use of automated external defibrillators. ***Resuscitation.*** 2005;67:S7-23.

12. ILCOR CoSTR Documents, in: ILCOR (Ed.), ***ILCOR Guidelines for CPR***, 2010.

13. Kordi M, Kluge N, Kloeckner M, Russomano T. Gender influence on the performance of chest compressions in simulated hypogravity and microgravity. ***Aviat Space Environ Med.*** 2012;83:643-648.

14. Koster RW, Baubin MA, Bossaert LL, Caballero A, Cassan P, Castren M, Granja C, Handley AJ, Monsieurs KG, Perkins GD, Raffay V, Sandroni C. European Resuscitation Council Guidelines for Resuscitation 2010 Section 2. Adult basic life support and use of automated external defibrillators. ***Resuscitation.*** 2010;81:1277-1292.

15. Krikscionaitiene A, Stasaitis K, Dambrauskiene M, Dambrauskas Z, Vaitkaitiene E, Dobozinskas P, Vaitkaitis D. Can lightweight rescuers adequately perform CPR according to 2010 resuscitation guideline requirements? ***Emerg Med J.*** 2013;30:159-160.

16. Lonergan JH, Youngberg JZ, Kaplan JA. Cardiopulmonary resuscitation: Physical stress on the rescuer. ***Crit Care Med.*** 1981;9:793-795.

17. Paradis NA, Martin GB, Goetting MG, Rosenberg JM, Rivers EP, Appleton TJ, Nowak RM. Simultaneous aortic, jugular bulb, and right atrial pressures during cardiopulmonary resuscitation in humans. Insights into mechanisms. ***Circulation.*** 1989;80:361-368.

18. Peberdy MA, Kaye W, Ornato JP, Larkin GL, Nadkarni V, Mancini ME, Berg RA, Nichol G, Lane-Trultt, T. Cardiopulmonary resuscitation of adults in the hospital: A report of 14720 cardiac arrests from the National Registry of Cardiopulmonary Resuscitation. ***Resuscitation.*** 2003;58:297-308.

19. Peberdy MA, Silver A, Ornato JP. Effect of caregiver gender, age, and feedback prompts on chest compression rate and depth. ***Resuscitation.*** 2009;80:1169-1174.

20. Rea TD, Eisenberg MS, Sinibaldi G, White RD. Incidence of EMS-treated out-of-hospital cardiac arrest in the United States. ***Resuscitation.*** 2004;63:17-24.

21. Rehnberg L, Russomano T, Baers J, Velho R, Cardoso R, Ashcroft A, Gehrke R, Dias M, Baptista R. What can CPR in simulated hypogravity teach us about CPR on Earth? ***Resuscitation.*** 2014;85:S6.

22. Robergs RA, Landwehr R. The surprising history of the “HRmax= 220-age” equation. ***JEPonline.*** 2002;5:1-10.

23. Russomano T, Baers JH, Velho R, Cardoso RB, Ashcroft A, Rehnberg L, Gehrke, RD, Dias MKP, Baptista RR. A comparison between the 2010 and 2005 basic life support guidelines during simulated hypogravity and microgravity. ***Extrem Physiol Med.*** 2013; 2:11.

24. Trowbridge C, Parekh JN, Ricard MD, Potts J, Patrickson WC, Cason CL. A randomized cross-over study of the quality of cardiopulmonary resuscitation among

females performing 30:2 and hands-only cardiopulmonary resuscitation. ***BMC nursing.*** 2009;8:6.

25. Van Hoeyweghen RJ, Verbruggen G, Rademakers F, Bossaert LL. The physiologic response of CPR training. ***Ann Emerg Med.*** 1991;20:279-282.

Disclaimer