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# How does rescuer fitness affect the quality of cardiopulmonary resuscitation?

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**How does rescuer fitness affect the quality of cardiopulmonary resuscitation?**

by

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ABSTRACT

INTRODUCTION: High quality cardiopulmonary resuscitation (CPR) is crucial for patients experiencing cardiac arrest. CPR quality declines within the first few minutes of a CPR bout. Limited research has examined the extent to which a rescuer's physical fitness predicts high quality CPR performance. It is also unknown how CPR quality is affected during both a realistic duration protocol and when rescuers switch compressors every two minutes, as recommended by the American Heart Association (AHA). The purpose of the present study is to determine the extent to which different measures of physical fitness predict high quality CPR performance when rescuers follow current CPR guidelines. METHODS: Subjects underwent a fitness assessment evaluating lower back muscular endurance, abdominal muscular endurance, upper body muscular strength, and upper body anaerobic power. At least 24 hours later, subjects returned to the laboratory for CPR testing. CPR quality was determined by compression rate (>100/minute), compression depth (>2 inches, or 50mm), and adequate (full) chest recoil between compressions. A CPR Quality Score was developed as the product of compression rate and depth. RESULTS: Thirty-three of 42 subjects were able to achieve a CPR Quality Score greater than 5000, the minimum needed to meet AHA recommendations. Higher anaerobic power and bench press scores were predictive of both high CPR Quality Scores ($R^2$=0.47) and compression depth ($R^2$=0.47). Gender (female) was predictive of better chest compression recoil percentages ($R^2$=0.15). CONCLUSION: Most rescuers can maintain high quality CPR if given two minute breaks between cycles. Rescuers with high anaerobic fitness and muscular strength may be able to provide higher quality CPR.

# CHAPTER I

# INTRODUCTION

Cardiopulmonary resuscitation (CPR) is a procedure that is performed by paramedics, and other rescuers, on patients during cardiac arrest. Most people have a general knowledge of how CPR is done, but the effectiveness of CPR is determined by several factors. Hand placement, depth of compression, rate of compression, and allowance for adequate chest recoil are all important for effective CPR (Travers, O'Connor, Chameides, Berg, Sayre, Berg, et al., 2010). There is evidence that high quality CPR improves survivability of cardiac arrest (Nolan, Hazinski, Billi, Boettiger, Bossaert, et al., 2010). Nearly all rescuers experience reductions in CPR quality during the initial minutes of resuscitative efforts (McDonald, Heggie, Jones, Thorne, Hulme, 2012). Quality of CPR also decreases in mannequin-based testing in durations ranging from 1 to 5 minutes (Hightower, Thomas, Stone, Dunn, March, 1995; Ochoa, Ramalle-Gómara, Lisa, Saralegui, 1998; McDonald et al., 2012; Ock, Kim, Chung, Kim, 2011).

Higher levels of fitness may increases a rescuer's ability to provide high quality chest compressions for longer durations, regardless of their level of medical training (Lucia, Heras, Pérez, Elvira, Carvajal, Álvarez, Chicharro, 1999; Pierce, Eastman, Mcgowan, Legnola, 1992; Ock et al., 2011). By determining the extent to which physical demands are significantly influencing the quality of CPR, healthcare providers may be able to better prepare themselves for the physical requirements of their jobs. Furthermore, knowing which specific muscle groups may be limiters of CPR performance could guide emergency responders on what exercise training to engage in.

Many studies have assessed the declines in quality associated with bouts ranging from one minute (Hightower et al., 1995) up to as many as 18 minutes (Lucía et al., 1999). Most studies, however, consisted of 9 to 12 minute bouts of continuous CPR (Heidenreich, Berg, Higdon, Ewy, Kern, Sanders, 2006; Bjørshol, Sunde, Myklebust, Assmus, Søreide, 2011; Pierce et al., 1992; Shultz, Mianulli, Gisch, Coffeen, Haidet, Lurie, 1995; Trowbridge, Parekh, Ricard, Potts, Patrickson, Cason, 2009). The duration of "real-world" CPR, though, can range from very brief (seconds) to time periods of over 40 minutes. During a typical cardiac arrest ambulance call, emergency responders will begin CPR upon arrival at the scene, and continue until the ambulance has arrived at the hospital. The total time between arrival of the ambulance and departing is referred to as the "scene-time". In 2013, the mean scene-time of a cardiac arrest 911 call was 17.2 minutes in Iowa. When added to the mean transport time of a cardiac arrest call (9.1 minutes), the total duration of CPR is over 26 minutes, assuming CPR is being performed throughout the call (personal communication with Terry Smith, Iowa Department of Public Health, Bureau of Emergency Medical Services). It is very important that the quality of CPR remain high throughout resuscitation efforts, even more so as CPR duration increases (Reynolds, Frisch, Rittenberger, Callaway, 2013). Optimal chest compressions help perfuse tissues with oxygenated blood, including the heart and brain. This can increase the likelihood of survival in a cardiac arrest patient.

Most studies examine rescuer fatigue and declines in CPR quality following single rescuer compressions for an extended period of time (2-18 minutes). During a cardiac arrest, emergency responders have protocols that dictate rescuers switch roles every two minutes, to minimize fatigue (Travers et al., 2010). To our knowledge, no previous research utilized a protocol consistent with that which would be used by emergency responders during an actual cardiac arrest scenario.

Most prior studies examining fatigue during CPR were conducted using the protocols released by the American Medical Association nearly 35 years ago, in 1980. These studies were based on a chest compression-to-rescue breath ratio of 15:2, at a rate of 80 compressions per minute (Lucía et al., 1999; Shultz et al., 1995; Hightower et al., 1995). None of these recommendations meet the current standards of the American Heart Association (AHA). As of 2010, the AHA advises a compression rate of at least 100 per minute and a ratio of 30 compressions to two breaths (Travers et al., 2010). In addition, previous studies used the compression depth of 40 mm (approximately 1.5 inches) in adults. This is less than the current AHA adult CPR guidelines of at least two inches (Travers et al., 2010). Collectively, the faster rate and the increased depth require a higher workload and are therefore more difficult to maintain than CPR in the past.

Recent studies have aimed to determine the impact of the most recent protocols on rescuer fatigue. Chest compression quality decreases in as little as two minutes of continuous compressions (McDonald et al., 2012). This is likely the reason the AHA and ARC recommends that rescuers switch roles (compressions or rescue breathing) every two minutes, or five cycles.

It has been determined by the AHA that most recent CPR recommendations are more conducive to survival of cardiac arrest when compared to the previous guidelines. It should be determined, then, if these are sustainable for realistic time periods of resuscitation. The metabolic demands of the AHA recommendations for CPR are presently unknown. Current standards involve more chest compressions, a faster compression rate, and a greater depth of compression, when compared to the protocols of the 1980's (American Medical Association, 1980). The AHA has also emphasized the importance of switching resuscitation roles (from administering chest compressions to rescue breaths) every two minutes. This recommendation was designed to reduce rescuer fatigue, which could offset the increased metabolic demands associated with deeper and faster compressions. No other research assessing rescuer fatigue has been found.

The goals of the present study are to 1) examine quality of CPR during a realistic protocol of 40 minutes duration, when switching resuscitation roles every two minutes, and 2) determine if various measures of physical fitness are associated with better CPR performance over this duration.

# CHAPTER II

# REVIEW OF LITERATURE

*Single-rescuer CPR quality decreases early during resuscitation*

Decreases in compression **depth** are usually the first aspect of insufficient quality that is seen during cardiopulmonary resuscitation (CPR). These decrements result after as little as one minute of CPR (Ochoa, Ramalle-Gómara, Lisa, Saralegui, 1998). Decrements in chest compression **rate** can also result after only two minutes (Ochoa et al., 1998). However, Ochoa and colleagues (1998) was the only group that found declines in chest compression rate in this brief amount of time. Another study also found decrements below the recommended rate after two minutes, but only in one subject (Bjørshol et al., 2011). These studies did not provide real-time feedback to the subjects, which may be a cause of the slower rate of compressions. Most (Lucía et al., 1999; Ock et al., 2011, McDonald et al.; 2012, Hightower et al., 1995; Riera, Gonzalez, Alvarez, Fernandez, Saura, 2007), but not all (Bjørshol et al., 2011) studies found decrements in compression rate over time.

Ochoa and associates (1998) found that the percentage of compressions with correct depth was 83% in the first minute. Further studies have supported these early declines in compression depth (Hightower et al., 1995; McDonald et al., 2012; Ock et al., 2011). Hightower and colleagues (1995) found only 62% of attempted compressions were of adequate depth by minute two, and only 18% by minute five. This study utilized a single rescuer, continuous compression design in which the rescuer was instructed to compress at a rate between 80 and 100 per minute and a depth of 1.5 inches. McDonald and colleagues (2012) reported only 52% of compressions were adequate during the first minute of CPR, and fell to 39% by the fifth minute. Ock and coworkers (2011) also found that compression depth decreased in the first minute. Only 78% of attempted compressions reached adequate depth. Both the McDonald (2012) and Ock (2011) studies utilized a continuous compression, single rescuer design in which the subjects were instructed to compress at a rate of 100 per minute and at least 2 inches (4-5 cm in the Ock et al. study). Conversely, Bjørshol and associates (2011) found that declines in compression depth within two minutes were rare. These findings may have been due to the subjects' professional status. The subjects in the Bjørshol study were trained paramedics, whereas the subjects recruited for the Ock study were recently trained in CPR. In the Bjørshol (2011) study, only one subject had a decline in compression depth within the first two minutes. All other subjects displayed a drop in depth between minutes 4 and 12 (Bjørshol et al., 2011). In the previously mentioned studies, each protocol utilized a single rescuer design, with the rescuer performing up to 13 minutes of continuous chest compressions.

It is unlikely that these results can be applied to an actual emergency situation, because ambulance crews consist of a minimum of two rescuers. Only in very unusual circumstances would a single rescuer be required to perform continuous chest compressions for a time exceeding two minutes. However, ambulance crews would likely perform repeated two minute bouts of CPR, with approximately two minute breaks between bouts.

Other factors determining CPR quality have been examined, including experience, age, gender, audio/visual feedback of performance, and position of the rescuer and mannequin. Of these, the greatest influence on CPR quality is real-time feedback. Showing a rescuer how they are performing during compressions causes them to alter the rate, depth, or recoil (i.e., chest decompression) accordingly. This dramatically improves CPR performance (Skorning, Beckers, Brokmann, Rörtgen, Bergrath, Veiser et al., 2010; Peberdy, Silver, Ornato, 2009; Fried, Leary, Smith, Sutton, Niles, Herzberg et al., 2011; Yeung, Meeks, Edelson, Gao, Soar, Perkins, 2009; Pozner, Almozlino, Elmer, Poole, Mcnamara, Barash, 2011). Increasing the quality, however, also means an increased workload. Feedback also caused subjects more fatigue (Skorning et al., 2010). This was likely due to the increased metabolic demand from sustaining faster rates and deeper compression depth. Furthermore, additional effort is required by the rescuer to lift their body weight completely off the chest following each compression.

Compression quality declines during protocols that require more compressions in a shorter amount of time (i.e., 30:2 versus 15:2) (Chi, Tsou, Su, 2010; Vaillancourt, Midzic, Taljaard, Chisamore, 2011; Trowbridge et al., 2009). Other studies examined demographic effects on CPR quality. Some research suggests that men demonstrate better CPR performance (Peberdy et al., 2009), while others show no difference between sexes (Ock et al., 2011; Ochoa et al., 1998). One study indicated that younger participants displayed better performance as well (Peberdy et al., 2009), while another found no differences (Trowbridge et al., 2009). It is possible that Trowbridge and associates did not find any age related associations with CPR quality due to the small age range of their subjects (22 to 35 years).

*Metabolic cost of CPR*

In terms of physical demands, CPR is not an aerobic activity. Quality CPR elicits a metabolic demand between 24% and 59% $VO_{2max}$ (Pierce et al., 1992; Lucía et al., 1998). These studies, utilizing older and less demanding CPR recommendations, elicited a $VO_2$ of 25 ml $O_2$/kg/min (Pierce et al., 1992) and 16 ml $O_2$/kg/min (Lucía et al., 1998). The differences in these obtained values are likely due to changes in protocol recommendations. (15:2 at 80 compressions per minute versus 80-100 compressions per minute, respectively). To our knowledge, no studies to date have established the metabolic cost of CPR at the current AHA recommendations. Based on the previous research, CPR quality measures decline within the first few minutes. This suggests that the metabolic pathways that are responsible for providing energy during CPR are anaerobic in nature.

Measures of subjective fatigue have also been examined during CPR. The most common measure of exertional fatigue has been the rating of perceived exertion (RPE) scale. Pierce and colleagues (1992) reported that subjects' mean RPE was 9.7 ±2.4, on a 20-point scale. In one study, subjects reported higher RPE values: 14.5 ±0.2 (Trowbridge, 2009). Furthermore, studies that utilized more current CPR recommendations obtained RPE values of up to 16.6 ±2.0 during the $6^{th}$ minute of CPR (Ock et al., 2011). McDonald and coworkers had subjects provide notification when they felt their fatigue was affecting their CPR performance (McDonald et al., 2013). In this study, 79% of the participants reported that fatigue influenced performance at some point during the five-minute protocol. Of these subjects, the average level of fatigue was 50 on a 100-point scale. The male subjects reported lower levels of fatigue than did females (76.2% compared to 80.5%).

Three studies examined the effect of compression to breath ratio on RPE. In the first of these, the highest compression to breath ratio (50:5) elicited the highest level of fatigue (mean of 4.4 ±1.54 on a modified Borg Scale (0-10) and the 15:2 group had a mean of 3.4) (Chi et al., 2009). The second study reported slightly lower levels of RPE in the 15:2 group, when compared to the 30:2 group (12.6 ±2.3 versus 12.9 ±2.4) (Vaillancourt et al., 2010). The third study did not see any difference in RPE after a 5-minute protocol (Betz et al., 2008).

Two studies examined the effect of feedback on subjective fatigue. The first, which utilized the Visual Analog Scale, reported no differences in subjective fatigue (Pozner et al., 2011). The second did not find any additional fatigue with feedback either (Skorning et al., 2009).

It has been suggested that local, or muscle, RPE is higher during CPR, when compared to overall RPE, which is an indicator of cardiovascular fatigue (Pierce et al., 1992). This finding suggests that other measures of physical fitness may predict better performance for longer durations of CPR.

*CPR quality decreases due to fatigue*

The studies mentioned above show that CPR quality decreases due to fatigue. Although it may seem intuitive, previous works have examined specific aspects of physical fitness that influence the longevity of quality CPR. Subjects with a higher $VO_{2max}$ may be able to provide CPR at a desired **depth** of compressions for longer periods of time (Lucía et al., 1999). This claim has also been contradicted, but in this study, subjects' $VO_{2max}$ was determined by a submaximal Astrand-Rhyming protocol, rather than gas analysis (Ock et al., 2011). This study also utilized other measures of physical fitness including strength, power, agility, and endurance. The only significant finding was that muscular strength predicted quality CPR for only the first minute of a bout. Subjects with a higher $VO_{2max}$ can also provide CPR compressions at a quality **rate** for longer periods of time (Lucía et al., 1999).

*Duration of testing protocols versus reality*

Of the studies reviewed, the longest duration of CPR tested was 18 minutes (Lucía et al., 1999). The shortest duration was two minutes (Verplancke, De Paepe, Calle, De Regge, Van Maele, Monsieurs, 2007; Foo, Chang, Lin, Guo, 2010; Riera et al., 2007; Vaillancourt et al., 2010). Several studies assessing various determinants of CPR quality utilized durations of 10 to 12 minutes (Bjørshol et al., 2011; Pierce et al., 1992; Trowbridge et al., 2009). A five-minute protocol has been used most frequently (McDonald et al., 2012; Hightower et al., 1995; Ochoa et al., 1998; Ock et al., 2011; Chi et al., 2009; Tsou, Chi, Hsu, Su, 2007; Betz, Callaway, Hostler, Rittenberger, 2008)

Recent data from the Iowa Department of Public Health reported that in 2013, there were 1157 cardiac arrest emergency calls in Iowa (verbal communication with Terry Smith). The average duration of CPR performed on the scene was 17.2 minutes, with 27 of these calls being over 40 minutes. The actual ambulance transport time of these calls is also important, since it contributes significantly to the overall duration of CPR. Of the 1157 calls, there was a mean transport time of 9.1 minutes. Thus, the overall average duration of CPR was 26.3 minutes. Consequently, there is a large discrepancy between actual CPR durations and durations used in the previous research. It is undetermined if research results discussed here are applicable to a real-life scenario. Determinates of CPR quality should therefore be assessed in a way more applicable to today's emergency responders.

It is currently unknown to what extent CPR quality declines with the current recommended protocols, and when the rescuers alternate roles (compressions or ventilations) every two minutes. It is also unknown what measures of physical fitness most affect CPR quality.

# CHAPTER III

# METHODS

*Experimental Design*

The aim of this study is to assess how a realistic CPR bout, in duration and rest periods, affects the quality of chest compressions. A second goal was to determine if high fitness, as assessed by measures of low back endurance, abdominal endurance and upper body strength and power, predict high quality CPR. Subjects completed two visits to the lab. The first visit involved completing a battery of fitness tests. The second test was a session of CPR on a mannequin consisting of two-minutes of chest compressions, followed by a two-minute rest period, with this sequence repeated for a maximum of 40 minutes. The mannequin quantified measures of compression quality for analysis.

*Subjects*

Fifty-four apparently healthy participants were recruited for this study, by soliciting participation (in person and email) from Kinesiology classes at Iowa State University. Subjects were all over the age of 18. Prior to the study, all subjects were certified in CPR, in order to ensure a consistent CPR skill level across all participants. Subjects were educated and certified in either American Heart Association Heartsaver-CPR or American Red Cross-CPR.

The following physical characteristics or conditions were exclusion criteria: under the age of 18, not certified in CPR, history of musculoskeletal problems in the upper extremities or chest, history of coronary vascular disease, intolerance to kneeling on hard surfaces, or presence of chest pain/discomfort with exertion. All subjects read and signed an informed consent form, as required by the Institutional Review Board at Iowa State University, prior to data collection. This study was given “exempt” status by the Institutional Review Board.

*Visit One*

Subjects’ resting blood pressure and heart rate were measured. Any abnormalities in resting blood pressure (systolic blood pressure >140 mmHg /110 mmHg) or heart rate (>100 beats/min) were considered exclusion criteria.

The subjects were instructed to refrain from engaging in any strenuous activity 24 hours, or consuming any caffeinated beverages in the 3 hours, prior to each visit. The first visit involved a series of tests to assess each subject’s physical fitness. CPR quality decreases within the first few minutes of CPR, suggesting that anaerobic metabolic pathways are likely the source of energy during CPR performance. To quantify anaerobic fitness, each subject performed an upper-body anaerobic power test, analogous to a Wingate test (Goslin, Graham, 1985), on a Lode cycle ergometer. Subjects were instructed to turn the arm crank on the ergometer for 10 seconds at minimal resistance to put the crank in motion. After this 10 second period, the “linear” mode of the cycle ergometer was activated, and subjects were encouraged to turn the pedals as fast as possible. In linear mode, the resistance increases linearly with the force provided by the subject. This mode quantified total work done by the subject in kJ. The subjects continued this test for thirty seconds. Subjects’ scores were reported as the total amount of work done throughout the duration of the test.

The erector spinae, pectoris major, and rectus abdominus are highly activated during a bout of CPR (Tsou et al., 2007). Thus, subjects completed muscular strength or muscular endurance tests for each of these muscle groups. For erector spinae, the Sorensen lower back test was utilized (Moreau, Green, Johnson, Moreau, 2001). This test consisted of maintaining the body at, or above, 180 degrees while prone with the pelvis supported and hips, knees, and feet secured. This test has been validated, extensively, as a measure of lower back muscular endurance by Moreau and associates (2001). For assessing pectoris major muscular strength, male subjects completed the maximum number of bench press repetitions with 80 pounds, while females used 35 pounds (Kim, Mayhew, Peterson, 2002). Subjects were required to keep a cadence of one repetition every 2 seconds. To assess each subject's rectus abdominus endurance, subjects completed the maximum number of crunches with their hands at sides, moving 4.5 inches forward (for one repetition), in one minute (YMCA, 2000).

Also during the first visit, subjects were familiarized with the CPR mannequin and data collection device (Q-CPR Adult Resusci Anne , Laerdal Medical Products, Wappingers Falls, New York). This system measures the chest compression rate, depth, hand placement, and qualitatively measures chest recoil. Fifty-four subjects completed the first visit to the laboratory.

*Visit Two*

The second laboratory visit involved a session of CPR on the resuscitation mannequin. Each visit was at least 48 hours after the previous session. Electrodes were attached to the subject to monitor three-lead ECG (LifePak 9, Physio Control, Redmond, Washington), and an automated blood pressure cuff (DinaMap XL, Critikon, Tampa, Florida) was secured to the subject's left arm.

Subjects were then given the current AHA recommendations for CPR, verbally, before the start of the CPR bout. Compression depth, rate, and recoil data were displayed on a monitor, which was viewable by the subject, for one two-minute cycle of CPR, to provide real-time visual feedback. Data were collected by the mannequin at 50 Hz for later assessment by members of the research team. Subjects were instructed to complete 10 two-minute durations of chest compressions, separated by two-minute rest periods. Each two minute compression period was intended to consist of continuous chest compressions at a rate of 100 compressions/minute and to a depth of at least two inches. Continuous chest compressions were used to simulate a scenario in which the cardiac arrest patient has received an advanced airway; thus, it is not necessary to account for time to give respirations. Other than the first two-minute cycle, the subjects were not allowed to monitor their performance or know how much time was left in each session.

The alternating compression-rest-compression design was intended to simulate the presence of a second rescuer, since most ambulance services are staffed with a two-person crew. Moreover, the current AHA recommendations dictate switching resuscitation roles every two minutes to minimize fatigue of the rescuers.

Blood pressure, measured by automated oscillometry, was monitored following each compression cycle, during the two minute rest periods. Heart rate, via ECG, were monitored continuously throughout the test and recorded concurrently with the blood pressure. The 6 to 20 RPE scale (Borg, 1970) was used following each set of compressions. Subjects reported scores for central (overall), lower back, and upper body RPE.

*Data analysis*

CPR quality was measured by compression depth, rate, and recoil. Depth and recoil data were separated into 15-second segments for each two-minute period using custom software. Compression rate was calculated manually for each minute of chest compressions, although little variability within subjects was seen. Heart rate measurements were taken in the 15 seconds following each cycle by a cardiac monitor (Lifepak 9,Physio-Control, Redmond, Washington). Blood pressure (SBP/DBP in millimeters of mercury), and heart rate (beats/minute) were reported as means ± standard deviations.

The SkillReporter® software (Laerdal Medical, Wappingers Falls, New York), created by the mannequin manufacturer and integrated into the mannequin, reports quantitative data as to the depth and rate of compressions. Mean compression depth was determined for each 15 second segment of all sessions. Mean compression rate was determined for the first 15 seconds of each minute of two times each cycle. The software also provided qualitative data regarding adequate recoil of compressions. These data were expressed as the percentage of compressions in which the subject allowed complete recoil for each 15 second segment of the cycle.

*Statistics*

All statistical analysis was completed with SPSS (version 21, IBM Corporation, Armonk, New York) computer software. CPR quality measures were expressed as the mean over the course of the ten CPR cycles. A CPR Quality Score was developed for each subject. This equation was intended to parallel the cardiac output equation (Cardiac Output (CO) = Heart Rate (HR) X Stroke Volume (SV)). Average compressions per minute (cpm) was considered analogous to heart rate and average compression depth was analogous to stroke volume. Therefore, the CPR Quality Score was the product of mean compression rate and mean compression depth.

Mean depth, mean rate, percentage of compressions with total chest recoil, and CPR Quality Scores were entered into least squares multiple linear regression analyses as dependent variables. Independent variables were the four fitness assessment scores, gender, height, weight, age, BMI, and length of CPR certification. Mean RPE scores for each cycle were assessed by repeated measures ANOVA. Statistical significance was determined by a p value of $<0.05$. Data are reported as means ± standard deviation.

# CHAPTER IV

# RESULTS

Fifty-four subjects were recruited for testing. Two subjects underwent fitness assessments but did not return to the laboratory for CPR testing and were excluded from analysis. Of the remaining fifty-two, 10 subjects were excluded due to their inability to compress the mannequin chest to a depth of at least two inches, for any one 15 second time segment, within the first two cycles of CPR. These subjects were allowed to continue the CPR test, but were excluded from analysis. These ten subjects had significantly smaller body mass than the remaining 42 subjects (57.2 ±5.6 kg vs 76.8 ±15.4 kg, $p < 0.001$).

Nine of these 42 subjects were not able to complete the entire 40 minute CPR protocol. The reasons given were upper body muscular fatigue (n=4), hand/wrist pain (n=3), and cardiovascular fatigue (n=2). The mean time until subjects withdrew from participation was 17.4 ± 5.6 minutes. Thirty-three subjects were able to complete the total duration of the testing protocol. All 42 subjects were included in data analysis (Table 1).

*Predictors of CPR Duration*

Independent variables included all those in Table 1 and were tested as possible predictors of total CPR test duration. Of these variables, only length of certification in CPR was a significant predictor of CPR duration ($p=0.005$; $R^2=0.154$).

*Predictors of CPR Quality*

Subjects included in this analysis (n=42) attained a CPR Quality Score ranging from 3793 to 6619. Mean CPR Quality Score was 5537±390. Based on current CPR recommendations of rate > 100 cpm and depth > 2 inches (50 mm), a rescuer needs to

Table 1. Subject and fitness assessment data.

| | **Male (n=20)** | **Female (n=22)** |
|---|---|---|
| Age (years) | 22 ± 1.7 | 21.3 ± 1.7 |
| Height (cm) | 181 ± 5.0 | 170 ± 6.6 |
| Weight (kg) | 90.1 ± 25.4 | 69.2 ± 9.0 |
| BMI ($kg/m^2$) | 27.3 ± 6.9 | 23.8 ± 3.0 |
| Length of CPR certification (months) | 27 ± 30.5 | 34 ± 31.7 |
| YMCA Bench Press (repetitions) | 35.1 ± 12.3 | 46.0 ± 21.0 |
| YMCA Crunch (repetitions) | 56.2 ± 14.2 | 50.3 ± 15.3 |
| Sorensen Test (seconds) | 93 ± 22 | 140 ± 47 |
| Anaerobic Power (kJ) | 12.1 ± 2.0 | 6.8 ± 1.5 |

achieve a score of at least 5000 to achieve acceptable CPR quality. Only eight subjects (19%) received a score less than 5000.

The combination of anaerobic power and bench press repetitions was the best predictor of the CPR Quality Score ($R^2$= 0.47). The anaerobic power test was the single best predictor ($R^2$=0.41) of high quality CPR performance. The regression model was Predicted CPR Quality = 4114.7 + (116.8 X Anaerobic Power (kJ)) + (8.1 X Bench Press (repetitions)). Gender, height, weight, BMI, YMCA bench press, and anaerobic power were significantly correlated with the CPR Quality Score ($p < 0.05$) and age trended toward significance ($p < 0.1$), yet did not enter the prediction model (Table 2).

*Predictors of Compression Depth*

Subjects included in the analysis (n=42) attained an average compression depth ranging from 37.9 (1.49 inches) to 66.2 millimeters (2.61 inches). Mean compression depth was 55.5±5.8 mm (2.19 inches).

A multiple regression analysis of the effects of age, weight, height, BMI, gender, length of certification, and the four fitness assessment scores (YMCA bench press test, YMCA crunch test, lower back endurance test, and upper-body anaerobic power test) on compression depth was completed. Of these measurements, gender, height, weight, BMI, anaerobic power, and bench press were correlated with CPR depth (Table 3). However, the only variables predictive of CPR depth were anaerobic power and bench press scores. Anaerobic power was the strongest predictor of compression depth ($R^2$=0.41). When bench press was added into the equation (with anaerobic power), there was a slight increase in predictive value ($R^2$=0.47). The final model was Predicted CPR Depth = 41.7 + (1.14 X Anaerobic Power (kJ)) + (0.078 X Bench Press (reps)).

Table 2. Predictors of CPR Quality Score (R values).

| Variable | CPR Quality Score |
|---|---|
| Gender | 0.463* |
| Age (years) | 0.25† |
| Height (cm) | 0.506* |
| Weight (kg) | 0.42* |
| BMI (kg/$m^2$) | 0.304* |
| Length of Certification (months) | -0.065 |
| YMCA Bench Press (rep.) | 0.269* |
| YMCA Crunch (rep.) | 0.179 |
| Sorensen Test (min.) | -0.078 |
| Anaerobic Power (kJ) | 0.641* |

* denotes $p<0.05$, † denotes $p < 0.1$

*Predictors of Compression Rate*

Subjects included in the analysis (n=42) attained an average compression rate ranging from 91.5 to 154.5 compressions per minute. Mean compression rate was 122.8±12.7 compressions per minute. Multiple regression analysis showed no significant predictors of CPR Rate. Gender, length of certification, anaerobic power, weight, and BMI trended towards being correlated with compression rate ($p < 0.1$) (Table 3). All correlations between variables are included in Table 4.

*Predictors of Adequate Compression Recoil*

Subjects included in the analysis (n=42) attained an average compression recoil percentage ranging between 24.1 and 100 percent. Mean compression recoil percentage was 90±15%. Multiple regression analysis showed only gender (female) to have predictive value for high compression recoil percentage ($R^2$=0.20). Other variables were correlated, but did not load into the regression equation (Table 3).

*Central RPE*

A repeated measures analysis of variance (RMANOVA) assessed the effects of time on central rating of perceived exertion (RPE). Overall RPE increased from 6 prior to cycle one, to 14.9±2.2 following the last cycle. Overall RPE increased initially, and plateaued at cycle 5 (18 minutes into the protocol) (Fig. 1). No significant increases were seen between cycle 6 (22 minutes) and cycle 10 (38 minutes).

*Lower Back RPE*

Following the 10$^{th}$ CPR cycle, mean lower back RPE had increased to 11.0±4.4, the resting RPE was 6. Lower back RPE increased significantly over time (Fig. 1) and plateaued at cycle 5. No significant increases were seen between cycle 6 and cycle 10.

Table 3. Predictors of CPR quality measures (R values).

| Variable | Compression Depth | Compression Rate | Compression Recoil |
|---|---|---|---|
| Gender | 0.458* | 0.255† | -0.451* |
| Age (years) | 0.249† | 0.088 | -0.011 |
| Height (cm) | 0.515* | 0.135 | -0.35* |
| Weight (kg) | 0.418* | 0.244† | -0.414* |
| BMI ($kg/m^2$) | 0.297* | 0.256† | -0.358* |
| Length of Certification (months) | -0.084 | -0.234† | -0.046 |
| YMCA Bench Press (rep.) | 0.264* | 0.165 | 0.252† |
| YMCA Crunch (rep.) | 0.157 | 0.004 | 0.173 |
| Sorensen Test (min.) | -0.077 | -0.148 | 0.374* |
| Anaerobic Power (kJ) | 0.638* | 0.238† | -0.296* |

* denotes $p<0.05$, † denotes $p < 0.1$

## Table 4. Correlation Matrix

| | CPR Quality Score | CPR Depth | CPR Rate | CPR Recoil | Anaerobic Power | Bench Press | Crunches | Sorenson Low Back Test | Age | Gender | Height | Weight | Body Mass Index | Length of Certification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CPR Quality Score | 1.00 | | | | | | | | | | | | | |
| CPR Depth | 0.99 ** | 1.00 | | | | | | | | | | | | |
| CPR Rate | 0.14 | 0.10 | 1.00 | | | | | | | | | | | |
| CPR Recoil | 0.00 | 0.01 | -0.15 | 1.00 | | | | | | | | | | |
| Anaerobic Power | 0.64 ** | 0.64 ** | 0.24 | -0.30 | 1.00 | | | | | | | | | |
| Bench Press | 0.27 | 0.26 | 0.17 | 0.25 | 0.03 | 1.00 | | | | | | | | |
| Crunches | 0.18 | 0.16 | 0.00 | 0.17 | 0.14 | 0.05 | 1.00 | | | | | | | |
| Sorenson Low Back Test | -0.08 | -0.08 | -0.15 | 0.37 | -0.45 ** | 0.27 | -0.09 | 1.00 | | | | | | |
| Age | 0.25 | 0.25 | 0.09 | -0.01 | 0.32 * | 0.29 | -0.13 | 0.25 | 1.00 | | | | | |
| Gender | 0.46 ** | 0.46 ** | 0.25 | -0.45 ** | 0.84 ** | -0.30 | 0.20 | -0.55 ** | 0.20 | 1.00 | | | | |
| Height | 0.51 ** | 0.52 ** | 0.13 | -0.35 * | 0.68 ** | -0.15 | 0.08 | -0.20 | 0.28 | 0.68 ** | 1.00 | | | |
| Weight | 0.42 ** | 0.42 ** | 0.24 | -0.41 ** | 0.51 ** | -0.06 | -0.05 | -0.39 * | 0.22 | 0.50 ** | 0.58 ** | 1.00 | | |
| Body Mass Index | 0.30 | 0.30 | 0.26 | -0.36 | 0.35 * | 0.01 | -0.09 | -0.39 * | 0.15 | 0.32 * | 0.30 | 0.95 ** | 1.00 | |
| Length of Certification | -0.06 | -0.08 | -0.23 | -0.05 | -0.05 | -0.05 | -0.09 | 0.15 | 0.25 | -0.12 | -0.03 | -0.01 | 0.01 | 1.00 |

* p<0.05, ** p<0.01

*Upper Body RPE*

Following the 10th CPR cycle, mean upper body RPE increased to 15.3±3.7. Upper body RPE increased significantly over time (Fig. 1). At cycle 10, upper body RPE was significantly higher than all other cycles (rest and 1 through 9).

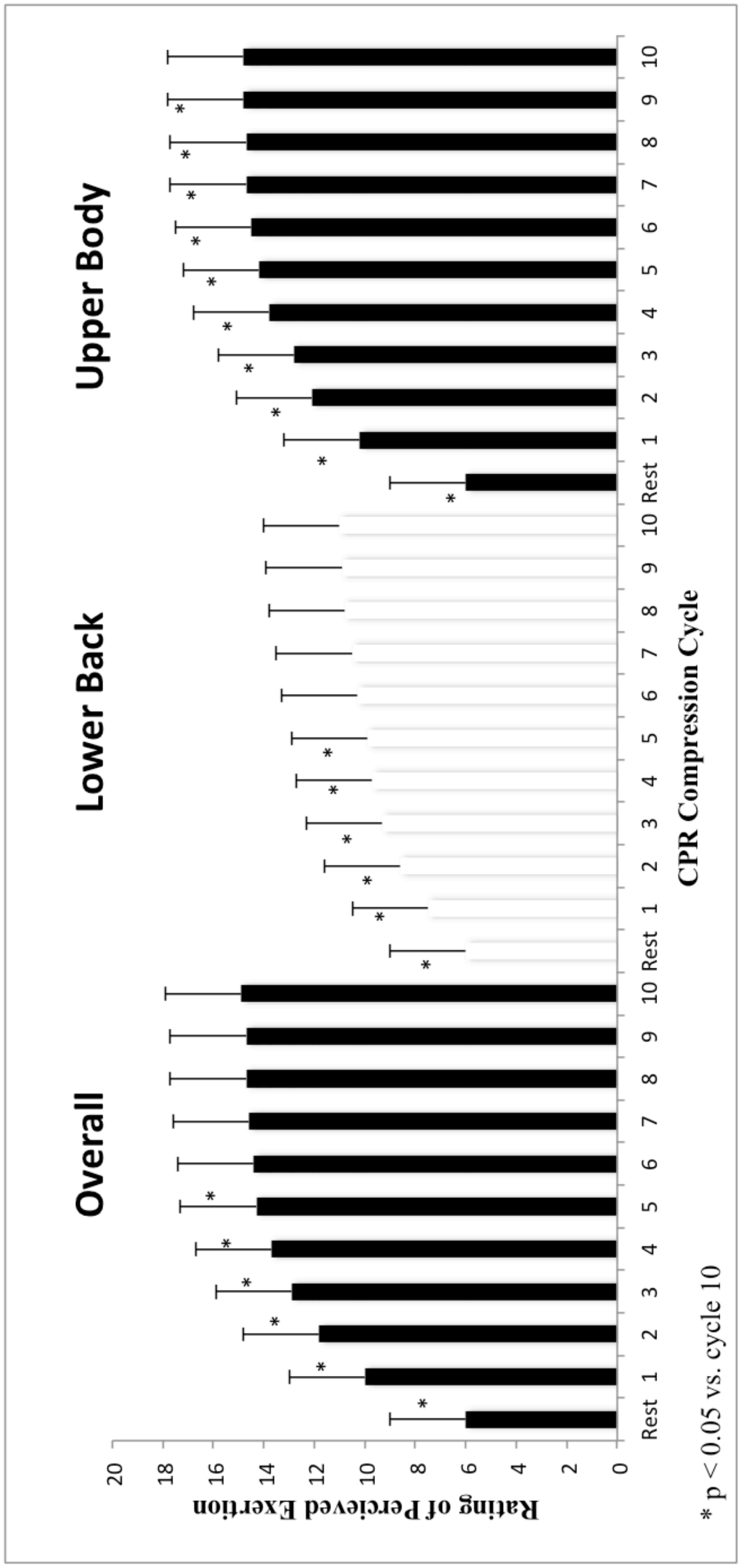


Figure 2. Overall, Lower Back, and Upper Body RPE

# CHAPTER V

# DISCUSSION

The objectives of the present study were to examine how trained CPR providers perform during an emergency situation of a realistic duration and to determine the extent to which physical fitness parameters can predict CPR performance. The long-term goal is to identify ways emergency responders can improve their quality of CPR, therefore improving survival of cardiac arrest. The results of this study support the hypotheses: 1) When rescuers are given two minute rest periods between compression cycles, the majority are able to continue providing high quality compressions longer than previously seen, and 2) Subjects with higher anaerobic fitness were more likely to have better CPR depth and provide better CPR quality.

*CPR Quality During a Realistic Protocol*

Over the course of the 10 chest compression cycles, 33 of the 42 subjects were able to complete the protocol. Twenty-eight of these subjects received a CPR Quality Score over 5000, which is the minimum calculated score one can receive if current CPR recommendations are met (100 cpm X 50 mm = 5000). Of the previous studies reviewed, many show decrements in CPR quality in the first few minutes of a testing protocol (Hightower et al., 1995, McDonald et al., 2012, Ock et al., 2011). In the present study, subjects were likely able to continue for longer durations than previously seen due to the rest periods given between cycles. The aforementioned studies used continuous CPR, or one person CPR, versus the two person CPR protocol used here. The two minutes of rest appears to be important for rescuers to recover during a strenuous cycle of CPR. A situation analogous to this scenario is that of sprint interval training. An individual can likely complete more 800 meter interval runs (lasting approximately two minutes), if given time to rest and replenish fuel sources between exercise bouts.

The present study utilized a much longer duration protocol than previous research. Of the extant studies reviewed, 18 minutes was the longest protocol seen (Lucía et al., 1999) and other studies utilized protocols as short as two minutes (Verplancke et al., 2007; Foo et al., 2010; Riera et al., 2007; Vaillancourt et al., 2010). Results in the Lucía et al. study (the longest protocol found) showed no significant decrements in either CPR rate or depth in an all-male subject group. This study, however, utilized recommended CPR criteria of the late 1990s (depth of 38-51 mm and rate of 80-100), requiring less physical strain than current CPR recommendations. The present study increased the CPR testing time to 40 minutes and many subjects were still able to continue high quality compressions at the end. More recent studies using shorter protocol durations also utilized the more challenging current CPR recommendations (i.e., deeper and faster compressions) than Lucía et al. (1999), but found decreases in adequate chest compression quality after only one minute of CPR (Vaillancourt et al., 2010). Based on the different recommended rates and depths of compression, decreases in compression quality measures are more likely with current recommendations. A possible explanation for a large portion of our subjects not experiencing declines in quality chest compressions is the fitness of the subjects.

It is difficult to compare the fatigue results of our study to results of studies completed either before 2007 or in countries other than the United States. This is due to different CPR recommendations utilized. Many studies also used vastly varying subject pools, specifically trained or untrained CPR providers. Furthermore, the present study removed subjects who were unable to compress the chest to a depth >50mm, for at least 15 seconds, from analysis. This was done to minimize the influence of such subjects fatigue data.

Compression rate was observed to increase, on average, over the course of the protocol. This is likely due to subjects either being unfamiliar with what 100 compressions per minute feels like or by compensating for perceived suboptimal compression depth.

*Physical Fitness Measures Predict CPR Performance*

Several studies have examined associations between various physical fitness parameters and high quality CPR performance. In these studies, the most common measure of fitness has been $VO_{2max}$, or aerobic capacity (Lucía et al., 1999; Ock et al., 2011; Russo, Neumann, Reinhardt, Timmermann, Niklas, Quintel et al., 2011). Results of these studies have been inconclusive, with only one seeing an association between high aerobic fitness and deeper chest compressions (Russo et al., 2011). Two studies did not see such associations (Lucía et al., 1999; Ock et al., 2011). One study assessing oxygen consumption during CPR speculated that the activity is likely more anaerobic in nature, since their subjects' $VO_2$ during CPR was near $VO_{2max}$ (Pierce et al., 1992). It is possible the present study elicited a greater aerobic response than earlier studies, as the protocol was much longer in duration. Other measures of fitness including muscular strength, muscular endurance, reactive agility, and power have been examined as possible predictors of CPR performance (Ock et al., 2011; Hansen, Vranckx, Broekmans, Eijnde, Beckers, Vandekerckhove, Dendale, 2012). Ock and associates (2011) found muscular strength to be a significant predictor of quality CPR depth, but failed to find significance in any other measure. A recent study also found ventilatory threshold to be a predictor of quality compressions; however, this study utilized less physically demanding CPR protocols (compression depth between 38-50 mm), and assessments were completed on a lower body cycle ergometer (Hansen et al., 2012). The present study also found muscular strength (bench press test) to be a significant predictor of CPR depth, explaining an additional 6% of variability when added to the anaerobic power score. The bench press test, however, is a much more CPR-specific movement than the hand grip dynamometry used in the aforementioned study. The present study also assessed upper body muscular power and endurance of lower back and abdominal muscles, but the assessments to detect these fitness levels differed greatly from previous works. The Ock (2011) study tested power of the lower body on a cycle ergometer. This differs from the present study in that the assessments used are more specific to the physical demands of CPR.

A novel finding of the present study was the predictive value of an upper body anaerobic power test and bench press test on quality CPR performance ($R^2$=0.47). The majority of the variability was explained by the anaerobic power test alone ($R^2$=0.41). This finding was not seen by Ock and colleagues (2011), as their assessment of muscular power was completed on a cycle ergometer. As CPR is not completed with the lower body, assessment of the subjects' upper body power generating abilities is more relevant to CPR performance.

The anaerobic power results may be due to the nature of metabolic systems used during CPR. Anaerobic metabolic pathways are responsible for producing high amounts of power, but also fatiguing most rapidly. This may be the reason other studies have seen declines in CPR performance within the first few minutes of a compression cycle (Ochoa et al., 1998). We speculate that individuals with high levels of anaerobic fitness are able to maintain the power needed to compress the chest to an effective depth, at an effective rate, longer than individuals with lower anaerobic capacities. It should be noted, again, that the high quality of CPR maintained in the present study may not have been possible without two minute rest periods following each cycle.

Power is a measure of work in a specific amount of time, and for the purposes of CPR, can be thought of as independent of strength. We did not find associations between anaerobic power scores and bench press scores (a strength-focused upper-body fitness measure) ($r=0.03$). This finding reinforces the specificity of an upper-body power test on CPR performance.

The present study utilized the CPR Quality Score to evaluate subjects' compression performance. While this measure suggests larger numbers mean better performance, this may not translate to reality. Any CPR score >5000 should be thought of as high quality, and greater scores are not necessarily indicative of higher quality compressions, as AHA recommendations are being met.

*Compression Depth*

Our results indicate the first measure of CPR performance to decline was compression depth. Similar depths were observed at the start of each cycle, but declined throughout each individual cycle (Fig. 2). While it was not possible to perform statistical analyses, due to several subjects withdrawing for various reasons, a general declining trend was observed within CPR cycles. Smaller declines in depth were observed from cycles one to ten. Other studies found gender (male) to be associated with increased compression depth (Russo et al., 2011), but this study utilized 30:2 and 15:2 compression

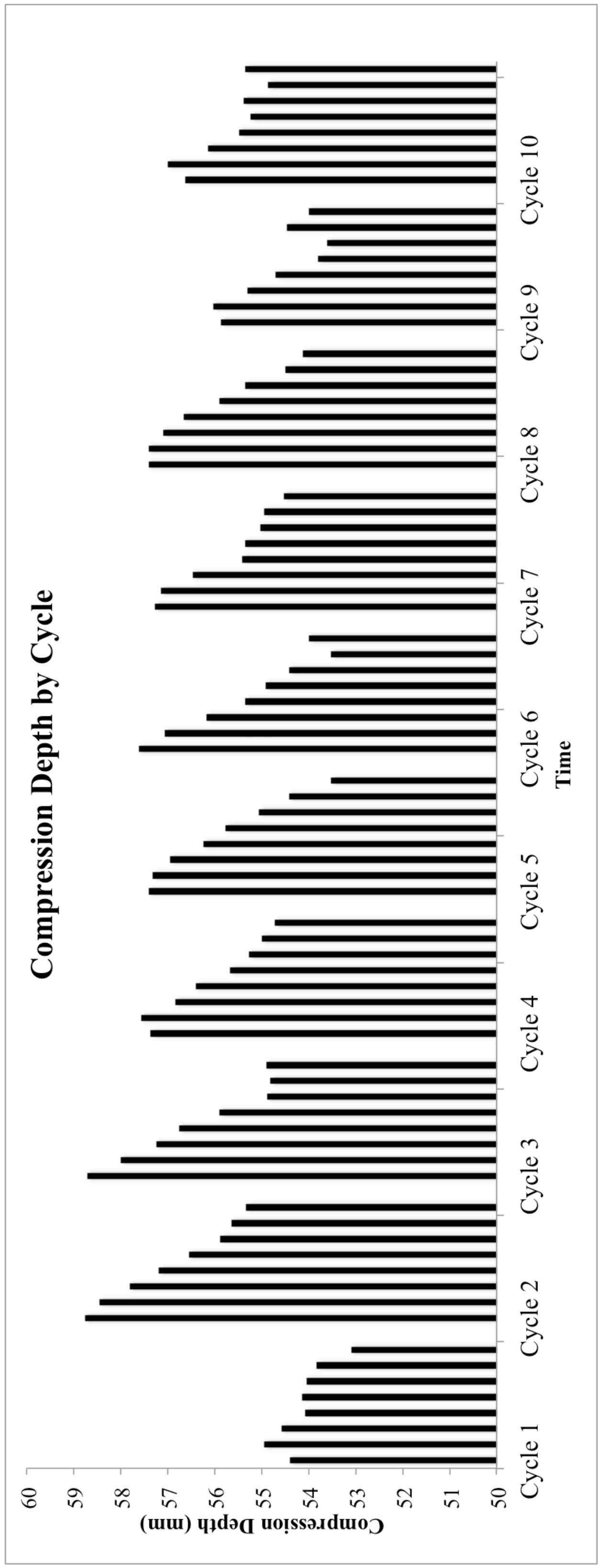


Figure 2. Compression Depth by Cycle.

to ventilation ratios for nine minutes without rest periods. A longer duration of compressions may have caused increased fatigue, and therefore decreases in compression depth.

*Compression Rate*

Previous research found females to compress at a higher rate when neither feedback nor instruction was given (Russo et al., 2011). In the present study, gender was not a significant predictor of chest compression rate. This is likely because very little physical ability is required to push the chest at a fast rate- all but one subject averaged over 100 compressions per minute over the course of the 40 minute protocol. Additionally, subjects were given feedback during the first cycle of CPR. Allowing subjects to see and feel what the recommended rate feels like may have contributed to an adequate overall rate throughout the course of the test.

*Compression Recoil*

Females tended to have higher percentages of total chest recoil. We speculate that this is related to the increased upper body mass of the male subjects. As subjects were kneeling on the floor and hinging at the waist, the repetitive motion of elevating the mass of the torso and arms could have caused increased fatigue.

*CPR Quality Score*

The CPR Quality Score equation used here is intended to be analogous to cardiac output. It is difficult to quantify good CPR beyond the goals of " >100 compressions per minute" and "> 2 inches deep." CPR compressions that do not reach 2 inches (50 mm) deep may still be effective, especially if the compression rate is increased. Compression depth is intended to approximate stroke volume, and compression rate parallels heart rate.

Together, these construct an equation similar to the cardiac output equation of heart rate X stroke volume. A measure such as this allows an individual to compensate for a decrease in compression depth by increasing the compression rate. While this equation is likely not valid for extremes of either rate or depth (e.g., extremely high compression rates may affect diastolic filling time), it seems to be a reasonable method for accounting for physiologically relevant deviations in compression measures.

Other studies utilized measures of quality such as the number of correct compressions within a given time (Vaillancourt et al., 2011), but this measure neglects the adequacy of compressions if they are slightly below perfect standards (i.e., 45 mm deep rather than 50 mm). The present CPR Quality Score does not ignore such compressions, including all compressions into the final score. Since high cardiac output is the goal of good CPR, subjects who compress at higher rates and depths will produce a higher cardiac output. One quality measure that is not factored into the present equation, however, is the total recoil of the chest following a compression. The automated mannequin system used here only allowed for qualitative analysis of this measure (i.e., complete or incomplete recoil). Here, compressions that did not return to <4mm deep were counted as having incomplete recoil. More pragmatically, a compression recoil to 90% of the original depth may not allow for full ventricular filling, but should not be viewed as completely ineffective.

Future studies should address the correlation between the CPR Quality Score and actual cardiac output, as well as possible methods for factoring chest recoil into the equation.

*Limitations*

Our study utilized a 60 kg spring in the chest of the mannequin, rather than the standard 45 kg spring. This was necessary due to many of our participants being more fit than average. All subjects were approximately college-aged, with many being from the Department of Kinesiology at Iowa State University. These students tend to exercise regularly and have good physical fitness. Thus, our pilot work found the standard 45 kg compression spring was not stiff enough to cause substantial fatigue in 40 minutes.

In the analysis of CPR compression data, it was determined that the timer built into the SkillReporter® software had a slight delay, causing subjects to do compressions for slightly longer than two minutes (<15 seconds). Rest periods were not affected by this delay.

The anaerobic power test on the ergometer only quantified the amount of power subjects produced in 30 seconds, but did not allow for measurement of fatigue resistance. Future studies should use additional fitness assessments to evaluate sustainability of a constant workload.

*Conclusions*

There are two major findings of the present study. First, most subjects are able to maintain high quality CPR for durations much longer than previously seen if given two minute rest cycles between compression cycles. Secondly, this is the first study to find physical fitness measures (upper body anaerobic power and bench press) that robustly predicted high quality CPR performance. These findings suggest emergency responders should engage in an upper body power training exercise program. This may lead to better CPR and may ultimately lead to improved cardiac arrest care.

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