Relative, Perceived & Actual Work of CPR in the Lay Population

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Cardiac arrest (CA) has a high incidence in the United States. With only a 10% average survival rate, out-of-hospital CA (OHCA) claims 366,000 lives annually. Cardiopulmonary Resuscitation (CPR) is a major predictor of outcome after OHCA. For CPR to be effective, rescuers must be able to perform high-quality chest compressions with regards to rate, depth, force, and release force. Performing CPR is physically demanding, with quality degrading as quickly as within the first 1-2 minutes after initiation. The American Heart Association (AHA) recommends rescuers alternate every 1-2 minutes, but rescuers may need to perform CPR for extended periods while waiting for further help, or for first responders to arrive.

Provider fatigue may be a major contributor to a decline in CPR quality. However, there is a lack of consensus over what provider-specific characteristics determine CPR quality and fatigue. Another factor affecting CPR quality is perceived fatigue, or how hard providers feel they are working. The effects of perceived fatigue combined with provider characteristics may affect CPR quality

We conducted a prospective, randomized, counterbalanced experimental study to investigate CPR quality over time in both males and females, and when performed with and without quality feedback. We assessed CPR quality based on the following metrics: compression rate, depth, force, and release force. We hypothesized CPR quality would vary between men and women and on the basis of quality feedback We performed secondary analyses to evaluate how other covariates (time, age, height, weight, BMI, body fat, $\dot{V}O_2$ max, $\dot{V}O_2$ during compressions,

muscular strength, muscular endurance, and RPE during compressions) affected CPR quality over a 10-minute period.

A total of 26 participants (age 25; IQR 22-37), 15 females (age 25; IQR 22-34), 11 males (age 24; IQR 21-60) completed the study. Three females could not perform 10 minutes of CPR. Rate declined over time, while perceived exertion increased, regardless of gender or feedback. Higher quality force and depth was associated with feedback, and higher muscular endurance. Lower release force (i.e., less leaning) was associated with females, leaner individuals, and higher muscular strength. These data suggest increased fitness levels may improve CPR quality metrics.

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Preface

I would like to thank my professors at Allegheny College, Dr. Humphreys and Dr. Cross, who believed in me even when my grades were sub-optimal and other remembers of the college suggested that the sciences 'just weren't for me.' I knew the sciences were for me, and you believed in me when others didn't, and for that I am forever grateful.

I would especially like to express my gratitude to my committee members, mentors, and my husband Mike for believing in me and supporting me throughout this endeavor. There have been many, many times when I did not believe in myself, and if it wasn't for your help and support, I would not have been able to accomplish this feat.

1.0 INTRODUCTION

Cardiac arrest (CA) has a high incidence rate the United States. With only a 10% average survival rate, out-of-hospital cardiac arrest (OHCA) claims 366,000 lives annually ("CPR Facts and Stats," ; Mozaffarian et al., 2016; Tsao et al., 2022; Vaillancourt, Midzic, Taljaard, & Chisamore, 2011; Virani SS, 2020). One of the major predictors of outcome from OHCA is whether the person receives bystander cardiopulmonary resuscitation (CPR) (Bobrow et al., 2011; Vaillancourt et al., 2011). Receiving bystander CPR doubles the likelihood of survival and good neurologic outcome ("CPR Facts and Stats," ; Nichol et al., 2008). Despite its importance to survival, only 40.2% of individuals receive bystander CPR in the United States ("CPR Facts and Stats," ; Tsao et al., 2022).

For CPR to be effective, the rescuer must be able to perform high-quality chest compressions, which require rapid rate and adequate depth of compression, as well as allowing for full chest recoil after each compression (Lin et al., 2016; Manders & Geijsel, 2009). Guidelines for what is considered adequate CPR have changed in recent years. In 2005, the American Heart Association (AHA) revised the CPR guidelines to increase the compression to ventilation ratio from 15:2, to a ratio of 30:2. This change was made in an attempt to improve patient hemodynamics by reducing interruptions between compressions (thus delivering more compressions per minute), and simplify the method of CPR with the hope of improving skills retention (Kwak, Kim, Baek, Kim, & Yim, 2016). In 2008, the AHA confirmed chest compression-only CPR (CCO-CPR) and standard- CPR (STD-CPR) have similar rates of survival (Sayre et al., 2008). In the 2015 updated AHA guidelines, adequate compression rate and depth is defined as 100-120 compressions per minute, at a depth of 2- 2.4” (5-6 cm). It is also within these guidelines that the AHA listed both CCO-CPR and STD-CPR as acceptable methods of application, emphasizing that untrained lay rescuers

should provide CCO-CPR until an AED is available, or a rescuer with additional training arrives (Kleinman et al., 2015).

Regardless of the CPR method (CCO or STD-CPR) employed, CPR is a physically demanding task. As the rescuer fatigues, CPR quality can rapidly degrade with regards to both compression rate and depth. Fatigue can also cause the rescuer to lean on the patient and not allow the chest to fully recoil. This degradation can begin as quickly as within 1-2 minutes after compression initiation (Foo, Chang, Lin, & Guo, 2010; Manders & Geijsel, 2009; Odegaard, Saether, Steen, & Wik, 2006).

Due to this swift rate of fatigue, the AHA recommends that rescuers alternate every 1-2 minutes when possible (Foo et al., 2010). However, a lone rescuer may need to perform CPR for extended periods while waiting for help, or for first responders to arrive. Within Allegheny County, EMS response times can vary from 4.8 to 17.8 minutes, and can reach upwards of 30 minutes in the Southwestern Pennsylvania region (P. V. Osdol, 2015; P. V. Osdol, October 09). EMS Response Times: Allegheny County, 2014. Retrieved from http://www.wtae.com/article/ems-response-times-allegheny-county-2014/7474784). Regardless, whether a layperson or medical professional is providing CPR, it is vital that quality CPR is performed throughout the entire resuscitation. This remains particularly true as the duration of CPR increases (Reynolds, Frisch, Rittenberger, & Callaway, 2013).

Historically, researchers have agreed that provider fatigue is the major contributor to a decline in CPR quality, regardless of the background of the provider (i.e. medical professional or lay individual) (Ock, Kim, hye Chung, & Kim, 2011). Potentially significant factors that may contribute to provider fatigue are individual-specific characteristics such as; gender, height, weight, body mass index (BMI), age, fitness level, muscle strength, and experience. However, which of these factors contribute to fatigue are not widely agreed upon. For example, some studies

have suggested that it is only a provider's muscular strength that contributes to his or her ability to perform adequate chest compressions (Abelairas-Gómez et al., 2018; Ock et al., 2011). Other studies have suggested that body weight plays a significant factor in CPR quality. For example, Hasegawa et al suggested that lighter weight individuals, regardless of gender should alternate performing CPR as frequently as every 1 minute due to the rapid decline in their CPR quality (Hasegawa, Daikoku, Saito, & Saito, 2014). There is a lack of consensus over what characteristics contribute to fatigue that leads to a decrease in the quality of CPR being performed. However, the fatigue experienced while performing CPR has not been adequately examined. One approach to assessing fatigue while performing CPR is to use a perceptual scaling metric such as the BORG 6-20 scale to quantify fatigue.

Ratings of perceived exertion can be defined as the 'subjective intensity of discomfort, strain, effort, and or fatigue that is felt by an individual during exercise' (Robertson & Noble, 1997). This perception is commonly assessed with the use of rating of perceived exertion (RPE) scales. One such scale is the BORG 6-20. The BORG 6-20 is a fifteen category numerical scale ranging from 6 - 20 with nine verbal descriptions within the scale with 6 indicating 'no exertion at all' to 20 indicating 'maximal exertion' (Robertson & Noble, 1997). It has been concurrently validated by correlating the RPE values with corresponding physiological variables such as heart rate (HR), ventilation, respiratory rate (RR), $\dot{V}O_2$, respiratory exchange ratio (RER), and blood lactate responses to both treadmill and cycle exercises tests. It has been validated in both male and female adults, across all fitness levels, and is considered to be an appropriate tool to assess RPE in a variety of aerobic conditions (Noble & Robertson, 1996; Robertson, 2004; Robertson & Noble, 1997). Because of this, the BORG 6 – 20 RPE scale could prove to have utility in assessing perceived exertion during performance of CPR.

Aerobic fitness is another potential factor that could affect fatigue during CPR. Estimating exercise capacity or cardiorespiratory fitness (CRF) from submaximal tests, exercise duration, or peak workload is useful in certain scenarios, but these estimations are often imprecise (ACSM, 2018). The standard error in estimating exercise capacity from some of the widely utilized estimation equations is at least 1 MET. While this measurement error is less significant when estimating the fitness of a healthy, young adult, an error of this size is much more significant when assessing individuals with lower exercise capacities (ACSM, 2018). The gold standard measurement of CRF, is maximal oxygen consumption ($\dot{V}O_2$ Max). $\dot{V}O_2$ Max is the product of maximal cardiac output (Q; L blood • min^{-1}) and arterial-venous oxygen difference (mL O2 • L $blood^{-1}$)' (ACSM, 2018)'. $\dot{V}O_2$ increases linearly as exercise intensity increases, and then plateaus when $\dot{V}O_2$ Max has been met. A similar relationship is seen with heart rate and RER as exercise intensity increases (Figure 1). When comparing $\dot{V}O_2$ Max between individuals of differing body weight, it is generally expressed in relative (mL • kg^{-1} • min^{-1}) rather than absolute (mL • min^{-1}) terms (ACSM, 2018). Individual and population differences in $\dot{V}O_2$ Max are primarily a result of differences in cardiac output (Q), meaning that one's $\dot{V}O_2$ Max relies on the functional capacity of his or her heart. $\dot{V}O_2$ Max is the single best measure of aerobic fitness. It is most commonly measured during a graded incremental treadmill test using open circuit spirometry, also known as indirect calorimetry (ACSM, 2018). Open circuit spirometry requires an individual to breathe through a low-resistance valve while either wearing a mask covering both the mouth and nose, or through a mouthpiece with a nose clip. While the individual breathes through the mask or nose piece, levels of expired carbon dioxide (CO_2), oxygen (O_2), and pulmonary ventilation are measured. Open circuit spirometry allows for not just the measurement of $\dot{V}O_2$ Max, but also determines the respiratory exchange ratio (RER), volume of expired air (VE), ventilatory-derived

anaerobic threshold (VAT), and the volume of exhaled carbon dioxide (VCO_2). A test may not be an accurate representation of an individual's $\dot{V}O_2$ Max due to inappropriate testing protocols, or a subject failing to put forth maximal effort. Because of this, at least one or more criteria are commonly chosen for quality assurance purposes to ensure a true $\dot{V}O_2$ Max has been achieved (Midgley, McNaughton, Polman, & Marchant, 2007).

These indicators include (ACSM, 2018):

- Plateau in $\dot{V}O_2$ with an increase in workload ($\dot{V}O_2$ no longer increases as treadmill speed or incline are increased)
- Failure of heart rate to increase with workload
- RPE of >17 on the Borg 6-20 RPE scale at peak exercise
- RER $\geq$ 1.10
- Post exercise lactate concentration of >8.0 mmol • L^{-1}

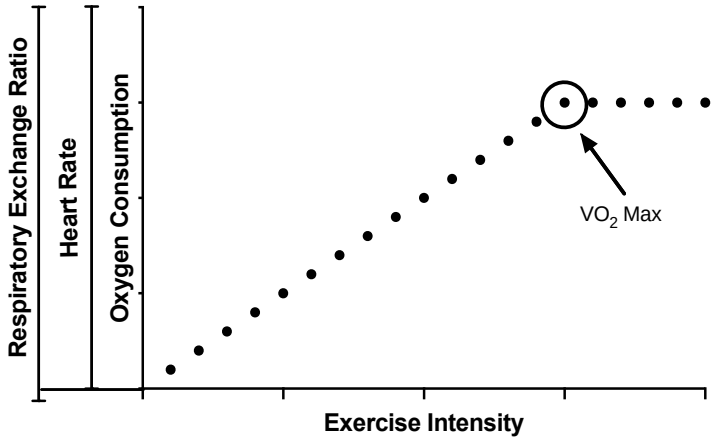


Figure 1 Oxygen Consumption Relative to Exercise Intensity

Muscular strength and endurance may also play a role in fatigue during CPR. Muscular strength, refers to an individual's ability to exert effort against a maximal force (Corbin, Pangrazi, & Franks, 2000). One way of measuring muscle strength is through isometric tests. A commonly

used measurement to assess isometric strength is the handgrip dynamometer (ACSM, 2018). A simple assessment of grip strength is a valid tool to predict an individual's upper body muscular strength and capacity (Curb et al., 2006). Muscular endurance, refers to an individual's ability to perform repeated muscle actions over a period of time until muscle fatigue (Corbin et al., 2000). A commonly used method to measure upper body muscular endurance, is with the push-up test where an individual performs as many push-ups as possible, until the subject fatigues (ACSM, 2018; Physiology, 2013). When providing CPR, overall strength and muscle endurance may both play a vital role in the ability to perform quality CPR.

Preventing decay in compression performance is vital to ensure the quality of CPR performance. It is well documented that CPR performance often deteriorates over time as a rescuer fatigues (Handley & Handley, 2003; Hostler, Wang, Parrish, Platt, & Guimond, 2005). One way to prevent or attenuate the decay in compression performance is to provide individuals with real-time CPR quality feedback. Unfortunately, rescuers are often unaware of their decline in performance (Betz, Callaway, Hostler, & Rittenberger, 2008). It has been demonstrated that when rescuers have access to real-time feedback during CPR, their compressions more closely conform to those as specified in current AHA guidelines (Abella et al., 2007; Betz et al., 2008; Hostler et al., 2011). Hostler et al. found that CPR feedback led to a lower decline in compression and ventilation quality over time compared to when no feedback was provided (Hostler et al., 2005). Other studies have further supported these results, and have suggested that when feedback is provided, the overall percentage of correct compressions (adequate rate and depth) is higher than when CPR is performed without feedback (Noordergraaf et al., 2006). A 2005 study by Williamson et al. showed that even in untrained individuals, audio feedback led to an increase in CPR quality (Williamson, Larsen, Tzeng, & Galletly, 2005). While the audio feedback was given

in-person, this concept may prove to be equally useful when over-the-phone CPR feedback is provided by a 9-1-1 operator.

Prehospital CPR performed by laypersons and EMS providers is one of the few modifiable factors that can contribute to an increase in survival from OHCA. In order to improve the quality of CPR delivered, it is imperative to first understand the underlying factors contributing to provider fatigue, so that future interventions can be developed to address these limitations.

1.1 RATIONALE

OHCA results in the death of 366,000 people annually, making it a leading cause of death in the United States ("CPR Facts and Stats," ; Mozaffarian et al., 2016; Tsao et al., 2022; Vaillancourt et al., 2011; Virani SS, 2020). Receiving high quality bystander CPR is a critical factor associated with increased survival. Improving the quality of CPR provided by bystanders is one way that survival rates may be improved (Bobrow et al., 2011; Vaillancourt et al., 2011). Receiving early CPR can double an individual's chances of survival ("CPR Facts and Stats," ; Nichol et al., 2008). Despite this fact, only about 40.2% of people who experience OHCA receive the immediate help and CPR they need before emergency responders arrive ("CPR Facts and Stats," ; Tsao et al., 2022). This makes early CPR the first and most important key to increasing survival rates of OHCA.

When the rescuer fatigues, and compression quality diminishes, compressions become less effective. In the common case of a single rescuer, he or she has no other option but to continue compressions regardless of their quality until other rescuers arrive.

Because provider fatigue is a primary contributor to a decline in CPR quality, it would be desirable to provide individuals with anticipatory guidance or training about how to mitigate

fatigue or how to improve CPR performance despite fatigue. However, it remains unclear how individual characteristics such as gender, age, height, weight, BMI, aerobic fitness, muscular strength, and muscular endurance all contribute to his or her ability to perform CPR. Understanding these relationships is essential for designing personalized countermeasures to fatigue during performance of CPR. Investigating these relations will allow for personalized interventions to mitigate fatigue and improve the quality of CPR.

1.2 GOALS AND OBJECTIVES

1.2.1 Objective 1.0

To compare compression quality between men and women over time across a 10-minute bout of CPR with regards to compression depth, compression rate, compressions force, and release force (an indicator of provider leaning) (Table 1). Compression rate and depth will be compared to AHA guidelines of 100-120 compressions per minute at a depth of approximately 5 centimeters ($\pm$1 cm). Because the amount of force necessary to compress the chest 5cm varies due to the difference in a victim's thoracic stiffness, there are not specific guidelines to define quality of force and release force. The change in compression force and release force will be measured as another means to measure provider fatigue over time.

1.2.1.1 Secondary Objective 1

To investigate whether CPR quality is influenced by other provider characteristics such as provider height, weight, BMI, $\dot{V}O_2$ Max, muscular strength, and muscular endurance.

1.2.1.2 Secondary Objective 2

To compare changes in the following responses to a 10-minute bout of CPR between men and women:

- **a.** Pre and post-CPR blood lactate levels.
- **b.** Changes in $\dot{V}O_2$ over time.
- **c.** Pre and post-CPR blood pressures.
- **d.** Change in global RPE over time.
- **e.** Changes in regional fatigue (RPE) pre-CPR, and immediately post-CPR in the following regions: lower back, triceps, abdominal muscles and knees.

1.2.2 Objective 2

To evaluate the differences in CPR quality when providers are given real-time CPR quality feedback during a 10-minute bout of CPR. CPR quality will be assessed based on compression rate, depth, force, and release force as previously described above (Table 1).

Table 1. Independent and Dependent Variables and Their Contribution to Hypotheses

Independent Variables	Dependent Variables
Gender	Rating of Perceived Exertion (RPE)
Height	$\dot{V}O_2$ During Compressions
Weight	Heart Rate During CPR
BMI*	Blood Pressure Pre & Post CPR
$\dot{V}O_2$ Max	Global RPE During CPR
Muscular Strength	Regional RPE Pre & Post CPR
Muscular Endurance	CPR Compression Depth
Time	CPR Compression Rate
CPR Quality Feedback	CPR Compression Force
	CPR Compression Release Force

*Individuals with a BMI >30 will be excluded from the study

2.0 BACKGROUND & HISTORY

2.1 HISTORY & EVOLUTION OF CPR

The first clinical description of mouth-to-mouth breaths were first documented in the modern medical literature as early as the 1730's, but it was not until the 1900's that resuscitation efforts began to resemble what we know as cardiopulmonary resuscitation (CPR) today ("History of CPR,"). In an effort to continually improve CPR quality and increase the rate of survival, the AHA and other organizations release new updates and recommendations about every five years.

CPR as we know it today, differs vastly from its first mention in the medical literature as mouth-to-mouth resuscitation in 1732 (Baker, 1971; "History of CPR,"). By the early 1900's resuscitation science began to increase in depth. In 1903, Dr. George Crile found that external compressions could successfully restore circulation in dogs (Crile, 1903). By 1933, Dr. William Kouwenhoven from Johns Hopkins University successfully resuscitated over 100 dogs by providing external compressions until a defibrillation shock could be administered (Beaudouin & Kouwenhoven, 2002; Crile, 1903). It was a respiratory researcher, Dr. James Elam who discovered that expired air sufficiently maintains adequate oxygenation in 1954 (Elam, Brown, & Elder Jr, 1954; Sands & Bacon, 1998).

Two years later, Dr. Elam in partnership with Dr. Peter Safar, successfully proved that mouth-to-mouth resuscitation, or 'rescue breathing' could be used as an effective lifesaving mechanism (Sands & Bacon, 1998). The following year, in 1957, the U.S. military adopted mouth-to-mouth resuscitation, and Dr. Kouwenhoven's team at Johns Hopkins created the first prototype of an external defibrillator ("History of CPR,"). Safar's work on mouth-to-mouth ventilation was published in the Journal of the American Medical Association (JAMA) in 1958. This landmark

paper was based on his research performed on sedated and paralyzed volunteers including medical students, nurses, and physicians. These volunteers were ventilated by mouth-to-mouth resuscitation and manual ventilation (Holder-Nielsen method) using a bell spirometer attached to a breathing mask (Acierno & Worrell, 2007).

The 1960's proved to be a time for rapid improvements in CPR. In 1960, with collaborators James Jude, and William Kouwenhoven, Safar combined mouth-to-mouth breathing and chest compressions to create what is now commonly known as cardiopulmonary resuscitation (CPR). Safar also wrote the book 'ABC of Resuscitation,' which established the basis of mass training of CPR the order of CPR to be A (airway), B (breathing), and C (chest compressions) (Acierno & Worrell, 2007). He would later become known as the Father of CPR. 1960 was also the year that the Resusci Anne was born. Dr. Safar, along with Drs. James Elam, and Archer Gordon, collaborated with toymaker Åsmund Laerdal to create Resusci Anne, a life-sized training manikin as a learning tool for CPR instruction ("History of CPR," ; Tjomsland, 2015). As of 1963, the AHA formally endorses CPR, and establishes its own committee dedicated to cardiopulmonary resuscitation (Field et al., 2010; "History of CPR,"). Three years later, the National Research Council of the National Academy of Science set the first standardized methods of CPR with the recommendation to perform compressions at a rate of 60 per minute, with a depth of 1.5-2 inches (3.8-5.1 cm), and a ratio of 15:2 for one rescuer, or 5:1 for two rescuers ("History of CPR," ; Hwang, 2013) (Table 2).

By the 1970's mass lay-person training sessions began gaining popularity, and the AHA published its first Advanced Cardiovascular Life Support (ACLS) textbook ("History of CPR,"). In 1972, Dr. Leonard Cobb launched Medic II, the first mass citizen CPR training program at the University of Washington. Within its first two years, Medic II trained over 100,000 people in CPR ("History of CPR,"). As CPR training continues to gain popularity, it wasn't until 1981, that King

County, Washington became the first region to provide dispatcher-assisted CPR ("History of CPR,").

Over the next few decades, refinements continued for CPR guidelines. In 2005, the AHA revised its guidelines to increase the compression to ventilation ration from 15:2 to a ratio of 30:2 (Hwang, 2013; Kwak et al., 2016). This change was made in order to improve patient hemodynamics and reduce interruptions between compressions, and with the hopes that simplifying the steps of CPR would also aid in skills retention (Kwak et al., 2016). In 2008, the AHA confirmed chest compression-only CPR (CCO-CPR) and standard- CPR (STD-CPR) have similar rates of survival (Sayre et al., 2008), and suggested that bystanders can skip rescue breaths and perform Hands-Only CPR. This was done with the hopes that by eliminating rescue breathing more people would be willing to perform CPR. Hands-Only CPR requires bystanders to dial 9-1-1 and provide high quality compressions until emergency responders arrive. In 2010, the AHA revised the recommended sequence of CPR procedures from Peter Safar's 'A-B-C' (airway, breathing, compressions) to the 'C-A-B' (compressions, airway, breathing) method. This was done due to the fact that chest compressions and early defibrillation are the most critical elements of CPR for patient survival (Field et al., 2010). Switching the order to C-A-B, allows for compressions to be initiated sooner, and no longer requires rescuers to start with the CPR procedures that are most difficult; obtaining an airway and delivering rescue breaths (Field et al., 2010). As of 2015, the current guidelines define adequate CPR as 100-120 compressions per minute, at a depth of 2- 2.4" (5-6 cm). The AHA also lists both CCO-CPR and STD-CPR as acceptable methods of application, emphasizing that untrained lay rescuers should provide CCO-CPR until an AED is available, or a rescuer with additional training arrives (Kleinman et al., 2015) (Table 2).

Table 2. Changes in CPR Guidelines

Guidelines	1966	1992	2000	2005	2010	2015
Compression Depth (cm)	1.5-2 in	4-5	4-5	4-5	$\geq$ 5	$\geq$ 5
Compression Rate (per min)	60	80-100	~100	~100	$\leq$ 100	100-120
Compression -Ventilation Ratio	15:2 for one rescuer; 5:1 for two rescuers	15:2 for one rescuer; 5:1 for two rescuers	15:2 for one or two rescuers	30:2 for one or two rescuers	30:2 for two or more rescuers	30:2 for two or more rescuers; or compression - only

2.2 EPIDEMIOLOGY OF CA

As of 2016, out-of-hospital cardiac arrests (OHCA), account for approximately 366,000 deaths annually. The three most frequent locations where OHCA occurs are at home or residence (69.5%), public settings (18.8%), and nursing homes (11.7%) (Virani et al., 2020). Despite advances in resuscitation efforts and CPR standards, only 10.4% those who suffer CA will survive, and only 8.2% will have good functional status at hospital discharge (Virani et al., 2020). Due to its high mortality and low rates of good functional outcome, CA is considered to be one of the most lethal public health problems in the United States (Meaney et al., 2013). CA accounts for more deaths than breast and prostate cancer, pneumonia, influenza, HIV, automobile and firearm accidents, and house fires combined (Meaney et al., 2013; Statistics, 2011). One of the key factors to increasing the survival rate of OHCA is its early recognition, and rapid initiation of bystander CPR.

However, CPR is intrinsically inefficient; even when performed properly CPR still only provides between 10%-30% of normal blood flow to the heart, and only 30%-40% to the brain (Halperin et al., 1986; Meaney et al., 2013; Michael et al., 1984; Ralston, Voorhees, & Babbs, 1984; Rubertsson & Karlsten, 2005). Because of this, CPR quality improvement is a primary focus for improving resuscitative efforts.

2.3 PHYSIOLOGY OF CPR

Compression Phase: As an individual administers CPR, the patient's heart is compressed between the sternum and spine, causing an increase in intrathoracic pressure and ejection of blood from the thorax, thus reducing its blood volume (Harris & Kudenchuk, 2018; Lurie, Nemergut, Yannopoulos, & Sweeney, 2016). Each compression causes the pressure in the aorta and right atrium to increase, and project blood from the heart towards the brain, coronary arteries, and other vital organs. One-way valves allow for the thoracic pressure to increase and project blood towards the body through the arteries by preventing blood from flowing backwards through the veins (Harris & Kudenchuk, 2018). With each compression of the heart, intracranial pressure (ICP) is also increased (Lurie et al., 2016).

Decompression or Recoil Phase: After a chest compression is delivered, blood is ejected from the heart to the brain, coronary arteries, and throughout the body (Lurie et al., 2016). The chest wall then passively recoils as the compression is released (Lurie et al., 2016). This allows the aortic valve to close and maintain a pressure that is higher than the intracardiac pressure (Harris & Kudenchuk, 2018). The recoil of the chest also creates a slight vacuum, causing intracardiac pressure to fall, and draws a small amount of air into the lungs and blood back to the heart (Lurie et al., 2016).

The decompression phase is also when the heart is perfused by the coronary arteries, as it is not perfused during the compression phase (Harris & Kudenchuk, 2018). Coronary blood flow is estimated using coronary perfusion pressure (CPP), which is calculated as the difference between the aortic and right atrium pressures (Harris & Kudenchuk, 2018). As the chest recoils from the compression, the aortic pressures increase above the aortic valve, while the intrathoracic pressure decreases, resulting in a positive CPP. Optimal perfusion occurs with the combination of compression forces that are strong enough to elicit an increase in aortic pressures and the consequent drop in intrathoracic pressures that occur after a compression is released (Harris & Kudenchuk, 2018). It is at this time when ICP is once again reduced. The change in ICP during the compression and decompression phases is what is commonly used to determine the level of cerebral perfusion during CPR (Lurie et al., 2016).

Chest compression fraction: Chest compression fraction is the percentage of each 1-minute interval during which compressions are provided, and it is highly associated with survival (Idris et al., 2015). Frequent or longer pauses between compressions leads to a lower compression fraction. When compressions are interrupted, the CPP rapidly declines, and it then takes multiple compressions to reach the same CPP prior to the pause (Harris & Kudenchuk, 2018). In a study of OHCA, individuals with an initial rhythm of ventricular fibrillation (VF) found that survival to hospital discharge was highest when compressions were administered between 60-80% of the time (Christenson et al., 2009).

Common Mistakes: According to AHA guidelines, compression depth should be approximately 5 cm deep. When chest compressions are not delivered at the right rate (too fast, or too slow) or at the right depth (too deep, or too shallow), patient outcomes are negatively impacted (Idris et al., 2015). Compression rates that are too high cause diastolic filling times to shorten, and adequate compression depth may not be met, which may prevent the chest from fully recoiling

between each compression (Lurie et al., 2016). Chest recoil may also be hindered if the victim's ribs are broken or if the chest is otherwise non-compliant (due to age, bone density, etc.). Additionally, if providers lean on the patient's chest, these factors will all markedly reduce perfusion pressures. Provider leaning is a common indicator of provider fatigue, which is one of the biggest factors in providing high quality CPR (Lurie et al., 2016). A study performed by Fried et al at the University of Pennsylvania, showed that at least 5 pounds of residual pressure (i.e. provider leaning) was observed in 91% of resuscitations, emphasizing that this is a highly prevalent problem and detrimental to CPR quality (Harris & Kudenchuk, 2018). Understanding how providers fatigue during CPR will provide insight to develop better mitigation strategies.

2.4 FATIGUE

Extreme tiredness or exhaustion, also known as fatigue, frequently occurs during exercise or activities requiring physical and, or mental exertion. Depending on the stimulus, performance can be limited by physiologic, metabolic, biomechanical factors, or a combination of the three (Noakes, 2000). There are five models commonly used to study and explain physiological and other training-induced changes that may be involved in delaying or preventing the onset of fatigue (Noakes, 2000). These models are:

1. **Cardiovascular / anaerobic model:** Exercise performance, particularly for endurance events is dependent on the maximal capacity of the heart to pump blood (cardiac output) to the muscles, and the ability of the muscles to efficiently utilize the supplied oxygen (Noakes, 2000). Fatigue ensues when cardiac output can no longer keep up with the oxygen demands of the working muscles, causing anaerobiosis, during which muscle work rates to decline (Noakes, 2000). Blood lactate concentration provides insight into an

individual's anaerobic work. During anaerobic exercise blood lactate levels increase, correlating with both heart rate and intensity (Ohkuwa et al., 2009).

2. **Energy supply and energy depletion model:** Exercises of varying durations and intensities can be limited by the body's ability to supply enough energy in the form of adenosine triphosphate (ATP) to the working muscles. Fatigue sets in when the amount of ATP supplied can no longer meet the demands of the working muscles.
    a. In the setting of an endurance event, carbohydrate oxidation is necessary to sustain muscle function. In this case, fatigue is caused by the depletion of carbohydrates from liver and muscle glycogen stores (Noakes, 2000).
3. **Muscle recruitment (Central fatigue) / muscle power model:** The central fatigue model suggests that exercise is limited by the recruitment of skeletal muscle, and muscle excitation and contraction (Noakes, 2000). Concentrations of neurotransmitters such as serotonin, dopamine and acetylchonine in the brain regulate the neural impulses sent to the working muscles. When these neurotransmitters are depleted, the muscle output can no longer meet demands necessary to sustain activity (Noakes, 2000). The muscle power part of this model suggests that exercise is limited by the working muscle's ability to contract to form cross-bridges and generate force (Noakes, 2000).
4. **Psychological / motivational model:** This model is sometimes included as a component to the central fatigue model. It suggests that exercise is at least partly limited by an individual's conscious effort to continue an exercise (Noakes, 2000).
5. **Biomechanical model:** Exercise is limited by the efficiency of the working muscles and their ability to work as elastic energy return systems. The more "elastic" the muscle is, the more economic the working muscle becomes. The more efficient a muscle becomes,

the slower the rate that fatigue-inducing metabolites accumulate, and the slower core body temperature increases, thus also decreasing the rate of fatigue (Noakes, 2000).

While each of these models have merit, there is not necessarily one model that is superior to the others. Each model is merely a concept intended to be utilized when determining what factors (physiologic, metabolic, biomechanical) determine performance and fatigue during a specific exercise or physical activity. Such concepts can be considered independently or in combination to describe the onset of fatigue.

2.4.1 FATIGUE & CPR

Performing CPR is physically demanding, in a real-life scenario it can also be mentally and emotionally taxing regardless of compression-to-ventilation ratios. Some evidence suggests that fatigue can occur as quickly as within 1-2 minutes of initiating 15:2 CPR. Rescuers are commonly unaware that they are fatiguing and as a consequence, their compression quality begins to degrade as well (Ashton, McCluskey, Gwinnutt, & Keenan, 2002; Betz et al., 2008; Hightower, Thomas, Stone, Dunn, & March, 1995; Ochoa, Ramalle-Gomara, Lisa, & Saralegui, 1998). This rapid decline in CPR quality is one of the reasons that the AHA recommends switching providers every two minutes. However, this is not a viable option in the case that only a single rescuer is available in a prehospital setting, prior to EMS arrival.

There is consensus that providers fatigue over time, but the factors that contribute to fatigue are still widely debated. A study done by Ochoa and colleagues found that CPR quality decreased within the first minute of compressions, and that the providers could not accurately perceive when their compression quality began to decline (Ochoa et al., 1998). A study by Hightower and colleagues showed similar evidence of CPR quality declining over time, and providers were unable to recognize when their compressions became inadequate (Hightower et al., 1995).

Work performed by Baubin et. al. argued that the duration an individual is able to sustain quality CPR is dependent on both the method of CPR as well as the rescuers' individual work capacity (Baubin et al., 1996). While this study was published in 1996, and therefore did not compare CPR methods that are aligned with current AHA guidelines (CPR 1:5 compared to 1:5 with the use of a plunger-like device that actively lifted the chest during recoil phase) the results based on rescuer work capacity are still relevant. The study found that regardless of the CPR method, participants frequently complained of pain in their arms, knees, and back. Duration of the resuscitation was influenced by the individual's work capacity and the CPR method, without any interaction between the two. Individuals with a higher aerobic work capacity, as measured by a symptom-limited maximal exercise cycling protocol, were able to perform CPR for longer durations than their lesser aerobically fit peers (Baubin et al., 1996).

Other studies have compared how provider physical fitness and biometric data affect CPR quality. In the study performed by Ochoa and colleagues that reported CPR quality decreases within the first minute, and providers lack awareness of compression degradation, found that these effects did not differ based on provider age, height, weight, gender, or profession (Ochoa et al., 1998). A study performed by Ock et al. noted that after adjusting for fitness level, there were no correlations between correct compressions and a provider's height, weight, and gender. There were also no correlations between number of correct compressions and a provider's muscle endurance, power or $\dot{V}O_2$ max. There were however, correlations between correct compressions and muscle strength over time (Ock et al., 2011). Conversely, a study performed by Shin et al. found that males performed better CPR with regards to both compression rate and depth during an 8-minute bout of CPR. Males were able to maintain adequate compressions per minute above 70% of time, whereas the percentage of adequate compressions performed by females decreased below 70% after 2 minutes of compressions. In addition, research performed by Ashton et al. found a significant

correlation between compression quality and the height and weight of a provider, and that fatigue has a greater impact on the effectiveness of compressions performed by females than males during a 3-minute session of CPR (Ashton et al., 2002). Another more recent study from 2021, found that higher anaerobic power and maximal bench press weight were predictive of higher CPR quality, specifically with regards to compression depth. That same study found that females performing CPR performed compressions with better recoil than males, suggesting that females may lean less on the victim than males (Lancaster, Stilley, & Franke, 2022). These results suggest that while fatigue adversely affects CPR quality regardless of gender, the reason for the greater effect seen in females may be due to the fact that they are generally smaller in stature compared to males (Ashton et al., 2002).

Other studies have produced similar results, suggesting that lighter individuals regardless of gender fatigue more quickly, and their CPR quality decreases more rapidly (Hasegawa et al., 2014; Russo et al., 2011). Results by Russo et al. found that a higher aerobic fitness and higher BMI had a positive correlation to CPR quality, and had slower rates of decline independent of gender. They also found that females performed CPR at a faster rate, but at a more shallow depth than males (Russo et al., 2011). One proposed theory as to why lighter individuals fatigue at a faster rate is that they have to work harder to produce the required force to adequately compress the chest, and must utilize the trapezius, abdominal rectus, external oblique, and rectus femoris muscles more so than their heavier counterparts (Hasegawa et al., 2014). The disagreement on what provider characteristics affect compression quality is present regardless of whether or not a provider is performing compression only CPR or 30:2 CPR.

2.4.2 FATIGUE DURING 30:2 VS. COMPRESSION-ONLY CPR

When comparing fatigue between performing 30:2 CPR or compression only CPR, quality is often quantified in terms of compression rate, compression depth, and chest recoil. Because providers do not provide breaths during compression only CPR, more compressions are provided per minute compared to 30:2 CPR, and thus reduced the amount of no-flow time (Abelairas-Gómez et al., 2018; Odegaard et al., 2006). However, more compressions per minute does not necessarily mean that these additional compressions meet the recommended depth. While compression only CPR provides more compressions per minute, compression depth often decreases faster as a function of time more so than when performing 30:2 CPR (Odegaard et al., 2006). In a lay population, Odegaard and colleagues found that compression depth began to decline as quickly as within one minute of initiating compression only CPR, with compression depth continuing to decline over the entire 5-minute CPR session. Whereas, when subjects performed 30:2 CPR, they were able to meet adequate compression depths for the entire session (Odegaard et al., 2006). Similar results were seen in a study that compared 2 minutes of compression-only CPR and standard CPR in an untrained lay population. Compression only CPR provided a higher total number of compressions, but the number of compressions delivered with appropriate depth decreased more rapidly during compression only CPR than during standard CPR (Nishiyama et al., 2010). Similar rates of fatigue are seen in the elderly population as well. In a study that recruited subjects between the ages of 60-84 years old, compression only CPR resulted in a larger number of compressions, but 30:2 CPR delivered a larger number of adequate compressions in all but the first minute of CPR (Heidenreich, Bonner, & Sanders, 2012). Rate of compressions did not change over time for either CPR method, nor did rate significantly differ between compression

only versus 30:2 CPR (82-95 compressions per minute, and 84-88 compressions per minute respectively) (Heidenreich et al., 2012).

One proposed theory is that performing 30:2 CPR gives providers a brief rest from compressions when providing breaths. Another theory is that providers are often overwhelmed by the idea of performing non-stop compressions and try to save their energy so that they can sustain CPR for the duration of the session (Odegaard et al., 2006). This idea is supported by some studies that have shown that providers perceive higher sensation of fatigue when performing compression only CPR compared to 30:2 CPR (Abelairas-Gómez et al., 2018).

Providers report a significant increase in perceived exertion over time regardless of the type of CPR being performed. Some studies argue that lighter individuals often report higher levels of perceived exertion than heavier individuals, regardless of gender (Hasegawa et al., 2014). Other studies have shown that RPE increases over time regardless of provider fitness level or characteristics (height, weight, gender) (Ock et al., 2011).

2.4.3 FEEDBACK VS. NO FEEDBACK

Providers are often unaware of the decline in their CPR performance. One potential way to mitigate this decline is through the use of real-time CPR feedback. Previous research has demonstrated that CPR quality improves when providers are given feedback in real time. Providers can receive feedback through a variety of ways including; 9-1-1 operator guidance; phone-based apps that can be downloaded from iPhone and Android App Stores; and defibrillators that have an accelerometer and may sometimes also measure impedance changes across defibrillator electrodes. These apps and defibrillators are able to provide real time audio and or visual feedback with regards to compression rate, depth, and release (to prevent leaning) (Hostler et al., 2011).

Three sites within the Resuscitation Outcomes Consortium (ROC) performed a prospective cluster-randomized trial to assess the effects of real-time CPR feedback provided to emergency medical services during out of hospital resuscitations. This study found that the presence of real-time audiovisual feedback improved CPR performance so that it more closely adhered to CPR guidelines (Hostler et al., 2011). Those who received real-time feedback had a lower mean compression rate (103 vs. 108 per minute) than those without, but had a higher chest compression fraction (percentage of time in which compressions are performed during resuscitation) (66% vs. 64%), performed deeper compressions (40 vs. 38 mm), and performed fewer compressions with incomplete release (i.e. leaning on the victim) (10% vs. 15%) (Hostler et al., 2011). Despite these differences, frequency of return of spontaneous circulation (ROSC) obtained in the field, presence of pulse upon hospital arrival, survival to hospital discharge, or awake status at discharge did not differ based on presence or absence of CPR feedback (Hostler et al., 2011). Similar results were seen in a lay population who performed compression-only CPR for 2 minutes on a manikin. The use of a CPR feedback/prompt device significantly improved the quality of compression-only CPR compared to compression-only CPR without the use of feedback (Liu et al., 2018). A study published in 2008, from Betz et. al. looked at the work of CPR during 5-minute bouts 15:2 and 30:2 CPR with real-time feedback in healthcare providers. They found that neither physical or perceived exertion changed when real-time feedback was provided, and that providers were able to perform more compressions per minute during 30:2 CPR without resulting in a decrease in compression quality (Betz et al., 2008).

2.4.4 ADDITIONAL FACTORS CONTRIBUTING TO FATIGUE

When considering the work of CPR, one must also consider additional external factors that can contribute to fatigue. For example, there are scenarios in which the events prior to, or during

CPR that may also contribute to provider fatigue, and a reduced ability to perform high-quality CPR. Water rescues for lifeguards are a prime example of these scenarios.

During a water rescue, lifeguards must first swim a great distance, often between 50-100 meters from shore to reach their victim and then safely return both of them to shore before initiating compressions (Kalén et al., 2017). There is some evidence to suggest that beginning the resuscitation prior to reaching shore is also a feasible strategy. In this situation, an individual is responsible for not only bringing themselves and the victim to shore, but to also provide ventilations while preventing the victim from aspirating or submerging beneath the water (Winkler et al., 2013). Asking an individual to perform high-quality CPR under these types of conditions is a daunting task. This is especially true because lifeguards are often required to make multiple rescue swims throughout their shift (Kalén et al., 2017).

In a simulation study with 20 lifeguards, Abelarias-Gomez and colleagues evaluated CPR quality after a realistic water rescue simulation with and without additional rescue equipment (fins and rescue tubes). Lifeguards performed 5 minutes of CPR on the beach as a baseline comparison. For the experimental rescue, they were required to perform a 50-meter sand run, swim 75 meters into the ocean to retrieve a rescue-manikin, bring the manikin back to shore and carry it 10 m into dry sand, and then perform 5 minutes of 30:2 CPR. After the water rescue, CPR quality decreased between 26-28% from baseline with regards to compression rate, depth, and chest recoil regardless of whether additional rescue equipment was used (Abelairas-Gómez et al., 2017). Other examples of external factors that may contribute to fatigue include potentially having to move the victim to a safe location to perform compressions, running to the victim's location (for example after notification of a cardiac arrest via PulsePoint, a 9-1-1 connected mobile device app that can alert lay individuals of a cardiac arrest in their area), or running to retrieve an AED. When considering CPR quality and fatigue, it is important to at least consider that these factors may have already

induced some amount of fatigue, putting a provider's ability to perform high-quality CPR at greater risk.

2.5 RATING OF PERCEIVED EXERTION

Perceived exertion can be defined as the subjective intensity of discomfort, effort, strain, and/or fatigue one experiences during exercise (Robertson & Noble, 1997). In the 1960's Swedish psychologist Gunnar A. V. Borg created and validated the first category scale of perceived exertion. It is his work that has laid the groundwork for perceived exertion research, and has led to our understanding of perceived exertion today (Robertson & Noble, 1997). Throughout his career, Borg continued to refine his category scales. He applied the concept that oxygen consumption and heart rate increase linearly to construct a scale that improved the linearity between the rating of perceived exertion and exercise intensity (G. A. Borg, 1982; Robertson & Noble, 1997). While many other researchers have also used this concept to create similar perceived exertion scales, Borg's Fifteen-category Perceived Exertion Scale (Borg 6-20 RPE) continues to be the most commonly accepted RPE scale for exercise testing and prescription in clinical and research fields, as well as in the fitness industry (G. Borg, 1998; Riebe, 2018; Robertson & Noble, 1997).

2.5.1 GLOBAL MODEL OF PERCEIVED EXERTION

The global model of perceived exertion considers how performance, physiological, and psychological factors affect an individual's overall or 'gestalt-like' response to both internal and external factors during exercise (Robertson & Noble, 1997). In 1996, Noble and Robertson created

a visualization model to depict the interrelationship between these three factors and how each of them contributes to an individual's global perceived exertion (Figure 2) (Noble & Robertson, 1996; Robertson & Noble, 1997).

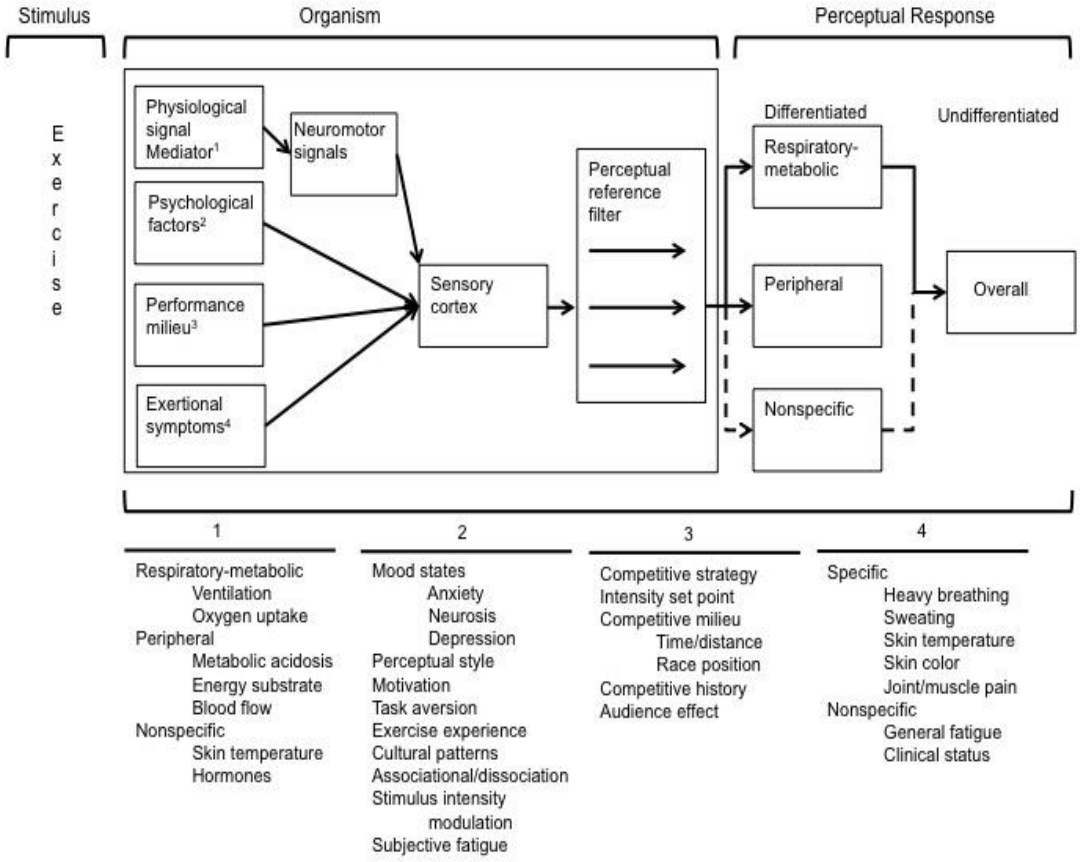


Figure 2. Reproduction of the Global Explanatory Model of Perceived Exertion (Noble & Robertson, 1996) *Model is interpreted from left to right

Initially, an exercise stimulus will elicit physiological responses, which are the initial mediators that determine the intensity of a perceptual signal (Robertson & Noble, 1997). These signals then work to modify the tension-producing properties of skeletal muscle. During exercise, a larger discharge of feed forward commands stemming from the motor cortex will evoke an increase in peripheral and/or respiratory muscle tension. Corollary pathways then carry copies of these central commands to the sensory cortex so that they may then be matched to components of

an individual's perceptual cognitive reference filter. The perceptual cognitive reference filter further refines these signals and modifies their intensities based on past and present events that regulate and characterize one's perceptual style (Robertson & Noble, 1997). The concluding perceptual response can either be differentiated to specific limbs that are actively engaged in the exercise activity, or it can present as an undifferentiated rating for the body as a whole (Robertson & Noble, 1997).

2.5.2 CATEGORY SCALING

Both clinical and research settings measure exertional perception using a procedure known as category scaling. Category scales are set based on a sensory response continuum divided into equal intervals. These scale categories are labeled with a set of numbers two of which categories are anchored to verbal descriptors of exertion. The distance between each category is assumed to correspond to equal intervals of change with regards to sensory response (Robertson & Noble, 1997).

2.5.3 BORG'S RANGE MODEL

Borg's Range Model is what provides the foundation for validating RPE scales. It acts as a model of how human sensory responses change with the presence of external physical stimuli and how this concept can be applied to perceived exertion as exercise intensity increases. This model follows two primary assumptions (Figure 3) (G. Borg, 1998; Robertson & Noble, 1997):

1) For any exercise intensity (from rest, to maximal intensity), there will be an equal, corresponding range of perceived exertion.

2) Both the perceptual range and intensity of these perceptual signals will be equal in clinically normal individuals through all exercise intensity levels (low to high).

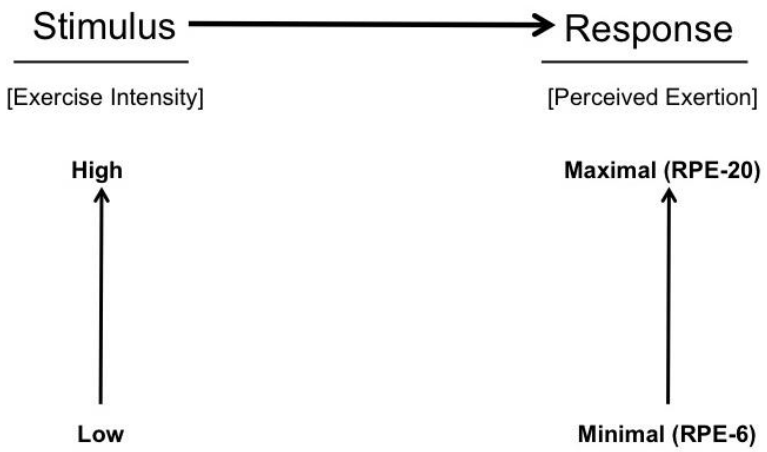


Figure 3. Borg's Range Model (Robertson & Noble, 1997)

The rationale behind this model is that these assumptions remain true across all exercise intensities (e.g. very low intensity to maximal intensity). As exercise intensity increases, there is a corresponding and equal increase in perception intensity from 'no exertion' to 'maximal exertion'. This model provides a standardized method to compare perceived-exertion responses between 'clinically normal' individuals who differ in their psychological, physiological and physical activity attributes (Robertson & Noble, 1997). For example, when RPE is at a set relative intensity it will be similar between individuals with a lower and higher aerobic fitness level, despite that a higher absolute intensity will be seen in the individual with the higher aerobic fitness level (Robertson & Noble, 1997).

2.5.4 EFFORT CONTINUA

The theoretical underpinning of applying RPE in clinical and research settings relies on the relationship between physiological responses and perceived exertion during an exercise stimulus (Robertson, 2004; Robertson & Noble, 1997). This rationale stems from Borg's original theory that a subjective response to an exercise stimulus involves three primary effort continua. These continua are physiological, perceptual, and performance. All of which, are influenced by factors including mood states, clinical status, and mode of exercise (G. Borg, 1998; Robertson, 2004; Robertson & Noble, 1997). Together, these three continua establish the connection between the physiologic demands of exercise, and the perception of exertion associated with exercise. They indicate that perceptual and physiological responses will provide the same information regarding exercise performance. This allows exercise prescriptions based on perception, to elicit the same responses as if it were based on physiologic responses (e.g. an exercise prescription based on an RPE range, instead of percentage of HR max) (Robertson, 2004; Robertson & Noble, 1997). The relationship between an exercise stimulus and physiological, perceptual, and performance continua can be seen in Figure 4.

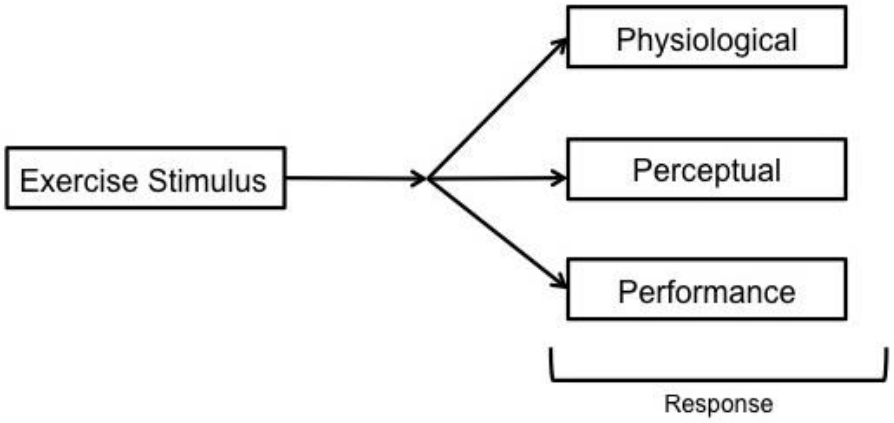


Figure 4. Effort Continua Model of Perceived Exertion (G. Borg, 1998; Robertson, 2004)

2.5.5 PHYSIOLOGICAL MEDIATORS OF PERCEIVED EXERTION

The various physiological mediators that regulate perceptual signals play a significant role when utilizing perceived exertion in clinical and research settings. These mediators can be classified into three groups: 1) nonspecific, 2) respiratory-metabolic, and 3) peripheral (Noble & Robertson, 1996; Robertson, 2004; Robertson & Noble, 1997) (Table 3). Non-specific physiological mediators of perceived exertion during exercise are considered to be more general or system-wide responses. While they are not directly linked to respiratory-metabolic or peripheral responses to exercise stimuli, they are still considered to be key physiologic contributors to overall perceived exertion. These non-specific mediators include temperature and hormonal regulation, as well as pain reactivity. The respiratory-metabolic responses are driven by mediators such as pulmonary ventilation (V_E), heart rate (HR), blood pressure (BP), oxygen consumption ($\dot{V}O_2$), and carbon dioxide (CO_2) production. The peripheral responses to exercise stimuli are driven by skeletal muscle composition in the trunk and exercising limbs (i.e. muscle fiber types and percentage of fast and slow-twitch fibers), as well as their contraction speed and efficiency (Noble & Robertson, 1996; Robertson, 2004; Robertson & Noble, 1997).

Table 3. Physiological Mediators of Perceived Exertion (Noble & Robertson, 1996; Robertson, 2004; Robertson & Noble, 1997)

Non-specific	Respiratory-Metabolic	Peripheral
Temperature regulation (both skin and core temperatures)	Oxygen consumption ($\dot{V}O_2$)	Blood glucose level
Cortisol & serotonin	Heart Rate (HR)	Blood flow to muscle
Pain	CO_2 production	Type of muscle fiber
Cerebral blood flow & oxygen saturation	Blood Pressure (BP)	Metabolic acidosis (lactic acid & pH)
Hormonal regulation (ex: β - endorphins & catecholamines)	Pulmonary Ventilation (V_E)	Muscle glycogen
		Free fatty acids

3.0 METHODS

We conducted a laboratory study in health adults to determine the relationship of individual characteristics with perceived fatigue and performance during CPR. The University of Pittsburgh Human Research Protection Office (STUDY19050375) approved this study.

3.1 SUBJECTS

Based on sample sizes from prior simulated CPR studies, we aimed to recruit 15 men and 15 women age 18 and up to participate in this study. We chose to focus on men and women who are representative of the general pipuation who might perform CPR. The screening process naturally excluded individuals who are very inactive, so highly active individuals (participate in > 300 minutes of aerobic and or resistance training per week), and individuals who are extreme athletes such as varsity collegiate athletes or professional athletes were also excluded from participation. We required all participants to be CPR certified (as verified by their American Heart Association or Red Cross CPR Certification Card).

We used the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and the updated American College of Sports Medicine (ACSM) guidelines for exercise participation to recruit individuals who may safely engage in physical activity (ACSM, 2018; Bredin, Gledhill, Jamnik, & Warburton, 2013). To minimize subject risk and to potentially reduce confounding variables we also chose to add the following exclusion criteria:

1. History of, or currently diagnosed with and/or being treated for cardiovascular diseases including: prior myocardial infarction (MI), coronary revascularization, congenital heart

disease, stroke, liver disease or impairment. This included taking medications that could potentially affect heart rate, such as beta blockers. The treadmill protocol used in this study required the participants to exercise until they have reached at least 85% of their age-predicted HR max. These medications make it unlikely that the participant would successfully reach this requirement.

2. Hypertension during screening, defined as systolic blood pressure greater than 139 mmHg and/or diastolic blood pressure greater than 89 mmHg.
3. Pregnancy
4. All forms of tobacco or nicotine use (smoking, chewing, vaping, etc.)
5. Obesity (BMI >30)
6. If the participant had any skeletal or muscular problems that would prohibit him/her from safely performing maximal exercise or CPR.
7. At the discretion of the study physician or clinician for any other medical condition or prescription medication that would make the protocol unsafe for the participant.

Upon completion of the study screening, participants received a remuneration of $30. They received an additional $30 upon completing all study visits for their participation via a VinCent payment card.

3.2 EXPERIMENTAL DESIGN

We performed a prospective, randomized, counterbalanced experimental study to investigate CPR quality over time in both males and females, as well as CPR quality with and

without CPR quality feedback. We assessed CPR quality based on the following metrics: compression rate, compression depth, compression force, and release force. We performed secondary analyses to evaluate how other covariates (time, age, height, weight, BMI, $\dot{V}O_2$ max, $\dot{V}O_2$ during compressions, muscular strength, muscular endurance, and RPE during compressions) affect CPR quality over time. We chose to counterbalance the order in which participants performed CPR with and without feedback to minimize order effect.

3.3 RECRUITMENT METHODS

We recruited participants through multiple media methods including directly approaching potential subjects (in-person), Department of Emergency Medicine website listings, the Pitt+Me Study Website, emails or listservs, or by contacting individuals who have previously participated in Applied Physiology Lab (APL) studies who have expressed interest in participating in future studies. We placed flyers throughout Oakland in various places of business, University of Pittsburgh Campus buildings, and within the local UPMC Hospitals (UPMC Presbyterian and UPMC Montefiore). All emails and flyers provided telephone and email contact information for the Applied Physiology Lab. Individuals who expressed interest were be encouraged to contact the Applied Physiology Lab, and underwent a short phone-based screening conducted by trained study staff members, or staff from the Pitt+Me Study Portal. The screening included a brief description of the study, and if the individual was interested, we asked a series of questions (See Appendix A: Phone Screening) to determine eligibility.

We invited potential subjects who met the phone-based eligibility criteria to schedule an appointment for further screening and enrollment. At this appointment, interested individuals

provided written, informed consent for continued participation before undergoing further screening. After providing informed written consent, participants completed a Physical Activity Readiness Questionnaire (PAR-Q+) (Appendix B: PAR- Q+) (Bredin et al., 2013), and a brief medical history intake form (Appendix C: Physician / APP Screening & Medical History), and underwent a basic physical examination by a study physician or clinician. Based upon the individual's responses to the medical history questionnaire and PAR-Q+, and physician/clinician screening if it was deemed the individual was healthy enough for participation, he or she was be enrolled in the study. If the individual did not meet all eligibility criteria, they were not enrolled in the study.

3.4 ASSESSMENT PROCEDURES

We conducted all assessment procedures for this study in the Applied Physiology Lab. Testing was conducted between 08:30 and 16:30 Monday through Friday. There was a maximum of four study visits (1) Consent and enrollment, 2) $\dot{V}O_2$ Max and Muscular strength testing, 3) First Performance of CPR, 4) Final Performance of CPR), each of which lasted between 60 and 90 minutes. Assessments included measurements of height, weight, body mass index, muscular strength and endurance, and maximal oxygen uptake. The experimental trials consisted of two CPR sessions performed on the Anne CPR Manikin fitted with the Little Anne QCPR Upgrade Kit and CPRmeter 2 compression puck (Laerdal, Wappingers Falls, NY). Participants were instructed to refrain from exercising, consuming alcohol, or taking pain medications for 24 hours prior, consuming caffeine for 6 hours prior, and eating or drinking for at least 3 hours prior to each of their study visits (with the exception of water). They were also instructed to wear lightweight, comfortable athletic attire and exercise shoes for each visit. If a participant was taking other

medications that are not considered an exclusion criteria we asked them to take their medication as directed by their doctor. If the medication must be taken with a meal, the visits were scheduled around the subject's medication schedule. There was a minimum of 7 days and a maximum of 14 days between each study visit.

3.4.1 Anthropometrics

We measured participant height to the nearest 1 cm with the participant standing barefoot in the upright position using a stadiometer (AnthroFlex, Minneapolis, Minnesota, USA). Participant nude weight was measured to the nearest 0.01 kg while the subject stood barefoot on an electric scale (Kern-KMB TM, Kern & Sohn GmbH, Germany). We calculated BMI ($kg \cdot m^{-2}$) using the standard BMI formula of dividing the participant's weight in kilograms (kg) by his or her squared height in meters (m^2). We also assessed the following body measurements:

Upper leg length: The participants sat on a chair with their legs bent at a 90° angle. Prior to the measurement participants sat up straight and relaxed their right leg. We took measures from the top-center of the patella to the inguinal crease, taken to the nearest 0.1 cm (Center for Disease Control, 2009).

Waist circumference: We measured waist circumference with participants standing in the upright position and measured from above the uppermost lateral border of the right ilium. The tape measure was held parallel to the floor and sat snugly, without compressing the skin. Measurements were taken to the nearest 0.1 cm (Center for Disease Control, 2009).

Hip circumference: We measured hip circumferences with the participants standing upright, arms hanging loosely at their sides, legs slightly apart. Measurement were taken from the maximal

circumference of the hips, taken to the nearest 0.1 cm (American College of Sports Medicine, 2018).

Chest expansion: We made two measurements of chest circumference; one during full inhalation, and a second during full exhalation. Participants stood upright, feet slightly separated. We measured from the xyphoid notch (joint between the bottom end of the sternum and the xyphoid process. Prior to the first measurement, we asked participants to take in a big breath and blow all the air out. They were then asked to take another large breath and hold it until the measurement is made. Immediately after, we told participants to exhale to their fullest extent and asked to hold until the measurement is made. The measurement was again be taken to the nearest 0.1 cm (Center for Disease Control, 2009).

Hip to Shoulder distance: We measured hip to shoulder distance to the nearest 0.1 cm. This distance was measured with the participants standing upright and was defined as the distance between the top of the iliac crest to the acromion process.

Shoulder to shoulder distance: Shoulder to shoulder distance was measured with the participant standing up, arms resting at their sides and measured from the back of the participant. We defined this as the distance between the acromion processes of the left and right shoulder, and again was measured to the nearest 0.1 cm.

Arm length: We measured arm length with the participant standing upright, arms resting comfortably at their sides. The distance was defined as the distance from the acromion process to the tip of the middle finger. Measurement was taken to the nearest 0.1 cm.

Upper arm length: We asked participants to stand in the upright position, with their right arm bent at a 90° angle at the elbow, with the right palm facing up. We measured from the uppermost edge of the posterior border of the scapula extending from acromion process to the tip of the olecranon process to the nearest 0.1 cm (Center for Disease Control, 2009).

Arm Span: We measured arm span with the participant standing upright, arms outstretched in a "T" position with their arms parallel to the ground, at shoulder height. Arm span was defined at the distance from the tip of middle finger of the left arm, across the nipple line of the chest to the tip of the right middle finger. Measurement was taken to the nearest 0.1 cm.

Body Fat Assessment: We assessed body fat percentage using the measurements from three skin fold sites. All measurements were made on the right side of the body with the participant standing in the upright position (American College of Sports Medicine, 2018). We placed calipers (Lang Technology Inc, Santa Cruz, California) directly on the skin surface, perpendicular to the skinfold, and at the halfway point to the crest and base of the skin fold. We 'pinched' the skinfold between pointer finger and thumb and held while reading the caliper. We held calipers in position for 1-2 seconds prior to reading the caliper measurement. Duplicate measures were taken at each site and we retested if measurements were not within 1-2 mm. To allow for skin to regain normal texture and thickness, each site was measured once in rotation with other site (American College of Sports Medicine, 2018). The following sites were measured:

Abdominal (men): We made a vertical fold 2 cm to the right of the umbilicus (American College of Sports Medicine, 2018).

Chest/Pectoral (men): We made a diagonal fold halfway between the anterior axillary line and the nipple (American College of Sports Medicine, 2018).

Suprailiac (women): We made a diagonal fold in line with the natural angle of the iliac crest within the anterior axillary line immediately superior to the iliac crest (American College of Sports Medicine, 2018).

Thigh (men and women): We asked participants to relax their leg (to not flex their quadricep muscles) while we made a vertical skin fold on the interior midline of the thigh, at the

midway point between the proximal border of the patella and inguinal crease (American College of Sports Medicine, 2018).

Triceps (women): We instructed participants to allow their arms to hang freely at their side. A vertical skin fold was made on the posterior line of the upper arm, halfway between the acromion and olecranon process (American College of Sports Medicine, 2018).

3.4.2 Physician / APP Physical Examination

A study physician or advanced practice provider (APP) conduced a brief physical examination on every participant. The examination included measurement of resting heart rate, blood pressure, and oral temperature, auscultation of the lungs, a 12-lead resting electrocardiogram (ECG) (Nasiff Associates, Cardio-Suite (tm) / Cardio-Card (tm) v6.34), and confirmed that the participant does not meet any of the exclusion criteria (APPENDIX C: Physician / APP Screening & Medical History). The 12-lead ECG was performed by a trained staff member, but interpreted by a study physician or APP. Preparation for the 12-lead ECG included: 1) shaving the electrode sites if necessary; 2) cleaning each of the electrode sites with an alcohol prep pad; 3) lightly rubbing each electrode site with a small abrasive pad to further remove dead skin; and 4) removing the electrode adhesive backing cover and placing the electrodes on the appropriate sites. We instructed participants to lay on the APL gurney in the supine position and rest quietly for approximately five minutes during the ECG assessment. A copy of the ECG was interpreted by a study physician / APP and saved in the participant's file.

3.4.3 Muscular Strength Test

We conducted all testing in the APL between 08:30 and 16:30 Monday through Friday. The muscular strength and endurance tests, and maximal exercise treadmill tests were always be the second visit for every subject. Each subject performed tests in the following order; maximal exercise treadmill test muscular strength test, muscular endurance test. There was a 20-minute rest period between each test. We used grip strength as a measure of overall muscular strength. Handgrip strength is considered to be a quick, valid tool to predict both an individual's overall muscle strength and functional capacity (Curb et al., 2006). Using a hand-grip dynamometer (JAMAR Hydraulic Hand Dynamometer, Performance Health, Akron, OH), participants had their grip strength measured in their dominant hand. The grip bar of the dynamometer was adjusted so that the second joint of the participant's fingers fit comfortably on the handle, and the dynamometer was set to zero. The participant was asked to hold the handgrip dynamometer in line with his or her body with the arm held at a right angle, and elbow at the side of their body, while not touching any other surrounding object. The participant was then instructed to squeeze the handgrip as hard as possible without holding his or her breath (to prevent the Valsalva maneuver) and hold their maximum effort for 5 seconds. The test was repeated three times with a 1-minute break between each test. The score will be considered the average of the three readings (to the nearest kilogram) (Gunn et al., 2017; Wood, 2008).

3.4.4 Muscular Endurance Test

We conducted all testing in the APL between 08:30 and 16:30 Monday through Friday. The muscle endurance test was started following a 20-minute rest period after performing the muscular strength test. Upper body muscle endurance was measured using the push-up endurance

test in both a standard and a modified (knee push-up) position. Each test was separated by a 20-minute rest period. The order in which participants performed the two push-up variations will be counterbalanced. When performing the standard push-up, participants started on the floor in the standard "down" position (hands positioned forward, in line with the shoulders, back straight, head in neutral spine position, on their toes, elbows flexed). When performing the modified push-up, participants started in the "down" position on the ground but in the modified "knee push-up" position (legs together, lower legs touching the mat, and head in neutral spine position). Participants raised their bodies by straightening the elbows and returning to the initial "down" position until their chin touched the mat. The maximal number of push-ups he/she can consecutively perform without stopping was considered as his/her score. The test was terminated when the subject was unable to maintain adequate technique for two repetitions (ACSM, 2018).

3.4.5 Maximal Exercise Treadmill Test

We conducted all testing in the APL between 08:30 and 16:30 Monday through Friday. The maximal exercise treadmill test and muscular strength and endurance testing will always be the order of testing during this study. A study team member ensured that the participant had not experienced any medical changes since the time of their consent, and all female participants underwent a urine pregnancy test. We gave participants a brief overview of the treadmill testing protocol and received instructions on how to use the BORG 6-20 rating of perceived exertion (RPE) scale prior to performing the test. Maximal oxygen consumption ($\dot{V}O_2$ Max) during the test was assessed using a metabolic cart (ParvoMedics TrueOne-2400, Sandy, UT). Prior to each test, we calibrated the system using standardized gases and calibration procedures. Participants were

fitted with a facemask covering both the nose and mouth. This ensured that any expired gases passed through the metabolic cart for analysis.

Subjects performed the modified Bruce treadmill protocol, an incremented graded treadmill exercise. The modified Bruce protocol consists of two, 3-minute warm-up stages (1.7 mph and 0% grade, followed by a 1.7 mph and 5% grade). After the warm up stages, both speed and incline increase every three minutes (ACSM, 2018) (Figure 5).

Stage	Speed (mph)	Grade (%)	Duration (minutes)
0	1.7	0	3
0.5	1.7	5	3
1	1.7	10	3
2	2.5	12	3
3	3.4	14	3
4	4.2	16	3
5	5.0	18	3
6	5.5	20	3
7	6.0	22	3

Figure 5. Modified Bruce Protocol (ACSM, 2018)

Prior to beginning the exercise test, we took a resting blood pressure and heart rate with the subject in the seated position. Heart rate was measured with a heart rate monitor (Polar H1, Bethpage, NY) worn around the participant's chest. Baseline blood pressure was measured using an automated blood pressure cuff (GE Carescape, Dinamap V100, Milwaukie, Wisconsin). We took lactate levels immediately before the start of the protocol, immediately after its completion, and 5 minutes after completion with a simple finger prick blood sample (Lactate Plus, Nova Biomedical Corp. Waltham, MA). Capillary lactate rather than venous lactate were taken as the risk for this procedure is minimal, and the correlation between the two blood lactate levels have

been deemed acceptable in previous literature (Kruse, 2011). Because the automated blood pressure cuff is not designed to take measurements while an individual is moving, exercise blood pressures were assessed manually until no longer audible (Graham-Field, Labtron, Atlanta, Georgia). During the exercise test we monitored the following vital signs; heart rate and respiratory rate documented every minute (monitored continuously), blood pressure every 3 minutes (when avle), and oxygen consumption every 30 seconds via open circuit spirometry (ParvoMedics TrueOne 2400, Sandy, UT).

We collected oxygen consumption data every 30 seconds using the ParvoMedics TruOne 2400 system and software during the treadmill test to determine absolute ($mL \bullet kg^{-1} \bullet min^{-1}$) $\dot{V}O_2$ max, and total energy expenditure (kcal). Ratings of perceived exertion were measured by asking participants to point to their RPE on the BORG 6-20 scale, and we measured them at baseline, within the last 15 seconds of each 3-mintue treadmill stage, and immediately upon test termination. Study staff verbally verified RPE ratings at each timepoint. The participant performed the treadmill test until he or she reached the point of volitional termination. However, the test was terminated at any point if the participant reported or showed signs or symptoms of exertion intolerance according to ACSM's general indications for stopping an exercise test (ACSM, 2018).

Lactate levels, heart rate and blood pressure were measured by study staff immediately after test completion, with a final lactate level measured again 5 minutes later (Lactate Plus, Nova Biomedical Corp. Waltham, MA). The following criteria were used to establish that the participant reached their $\dot{V}O_2$ Max: the participant must rate their exertion as 17 or higher on the BORG 6-20 scale and meet at least two of the following physiologic criteria: experienced a plateau in $\dot{V}O_2$ despite an increase in workload, respiratory exchange ratio (RER) greater than 1.10, blood lactate level greater than 8-9 mmol, or failure of heart rate to increase with workload.

Upon completion of the treadmill procedure, we removed the facemask from the participant's face, and he or she was permitted to cool down actively and or passively at their preference. For the first five minutes of recovery, heart rate was monitored every minute, after which, heart rate and blood pressure will be monitored every five minutes, for a minimum of 15 minutes, or until HR returned to a range within $\pm$ 10 beats per minute of the subject's pre-test resting value or dropped below 100 beats per minute.

3.4.6 Measures of Discomfort & RPE

The definition of RPE and its standard instructions (APPENDIX D) on how to use the BORG 6-20 RPE (G. Borg, 1998) (Figure 6) were read to each participant prior to performing the maximal exercise treadmill test, and before each bout of CPR. During the treadmill test, we instructed participants to point on the BORG 6-20 RPE Scale to rate their overall body perceived exertion within the last 15 seconds of each 3-mintue treadmill stage, and immediately following completion of the exercise test. Perceived exertion values were verbally verified by a study staff member at each point. The BORG 6-20 RPE scale was placed on a bulletin board in front of the treadmill so that the subject could reference the scale periodically throughout the test. Treadmill exercise is known to potentially produce stronger sensations of exertion throughout the entire body, rather than within a specific region (i.e., the legs) often seen in cycling exercise. Because of this, the global measure of exertion may be more useful than using a differentiated RPE associated with the legs or chest (Robertson, 2004).

During the CPR sessions, we assessed multiple RPE's to gauge global fatigue during prolonged CPR. Immediately after completing 10 minutes of CPR, regional fatigue was also be assessed. Overall body RPE was measured at baseline prior to beginning compressions, every 2 minutes during compressions, and immediately after the CPR bout completion. During CPR, an

enlarged version of the BORG 6 – 20 scale was again placed in front of the participant for their reference. Participants were asked to point on the BORG 6-20 RPE Scale to rate their RPE. To measure potential regional pain or fatigue, the BORG 6-20 Scale was also be used to measure fatigue in the participant's lower back, triceps, abdominal muscles, and knees immediately following CPR completion. Regional fatigue was rated by participants in the following order; staff members first asked which region they are felt the most fatigued, and to rate that region on the BORG 6-20 scale. They were then asked to rate their fatigue in the following order; lower back, triceps, abdominal muscles, and then knees. To reduce distraction during the CPR bouts, regional assessments were only be taken at baseline, and immediately upon CPR bout completion.

To measure whether individuals experienced pain or discomfort in other regions of their body after performing CPR, participants were also asked to complete the location and current intensity portion of the Brief Pain Inventory Short Form (Appendix E) within five minutes of completing their bout of compressions. The Brief Pain Inventory Short Form is a validated tool commonly used to measure the history, location, intensity, and quality of an individual's pain (Cleeland & Ryan, 1994). Participants were told to shade the areas in which he or she feels pain and put an "X" on the area that hurts the most. They then rated their pain from "0" indicating "No Pain," to "10" indicating "Pain as Bad as You Can Imagine."

3.4.7 CPR Performance

There were two visits in which participants will perform a 10-minute bout of CPR. One bout performed with guided feedback, with regards to compression rate, and depth. The other bout performed without real time guided feedback. The order in which participants performed the CPR bouts was counterbalanced. Both bouts of CPR were performed on a Little Anne CPR Manikin fitted with the Little Anne QCPR Upgrade Kit and CPRmeter 2 compression puck (Laerdal,

Wappingers Falls, NY). Little Anne is a CPR manikin fitted with Quality CPR (QCPR) feedback technology that collects information with regards to total number of compressions, compression force, rate and depth. The CPRmeter 2 is commercially available, commonly used clinical feedback transducer that is frequently used in CPR practice. The puck-shaped device has the capability to give feedback to providers with regards to the rate and depth of compressions (Figure 7). When paired with the CPRmeter app (Laerdal, Wappingers Falls NY) the Little Anne QCPR manikin and CPRmeter 2 are able to give providers summative feedback of the overall quality of the compression rate, depth, and compression fraction as well as collect continuous CPR metrics. These data can then be exported from the CPRmeter app for further analysis (see section 3.4.8 Data Analysis for further data export information). During the visit that a participant performed CPR with feedback, they were able to see the screen of the CPRmeter 2 and its output (Figure 7).

During the visit that a participant performed CPR without feedback, we covered the screen of the CPRmeter 2 with opaque tape so that CPR quality data was recorded without the participant seeing the CPR feedback on the screen. The use of the CPRmeter 2 during both CPR sessions ensured that the presence or absence of the CPRmeter would not confound results. While the CPRmeter2 shows an 'inactivity timer' it does not show the actual duration of the bout of CPR. Therefore, participants did not have access to a clock or timer during either bout of CPR.

At the beginning of each visit, a urine pregnancy test was performed on all females, and a study member ensured there have not been any medical changes since the time of consent. Participants then donned a heart rate monitor (Polar H1, Bethpage, NY), and respiratory face mask (Parvo Medics TrueOne 2400, Sandy UT), and positioned themselves beside the manikin. Upon positioning, a researcher again described the BORG 6-20 RPE Scale (Figure 6, Appendix D), and ensured the subject had no further questions. An enlarged copy of the BORG 6-20 Scale was placed in front of the participants so that they could reference it at any point throughout the study. Prior

to beginning compressions, a study team member used a goniometer (JAMAR, Performance Health, Akron, OH) to measure the subject's arm, hip and spine angle relative to the manikin to evaluate body positioning during compressions.

#	**Level of Exertion**
6	No exertion at all
7	-
7.5	Extremely light (7.5)
8	-
9	Very light
10	-
11	Light
12	-
13	Somewhat hard
14	-
15	Hard (heavy)
16	-
17	Very hard
18	-
19	Extremely hard
20	Maximal exertion

Figure 6. BORG 6-2 Rating of Perceived Exertion Scale (G. Borg, 1998)

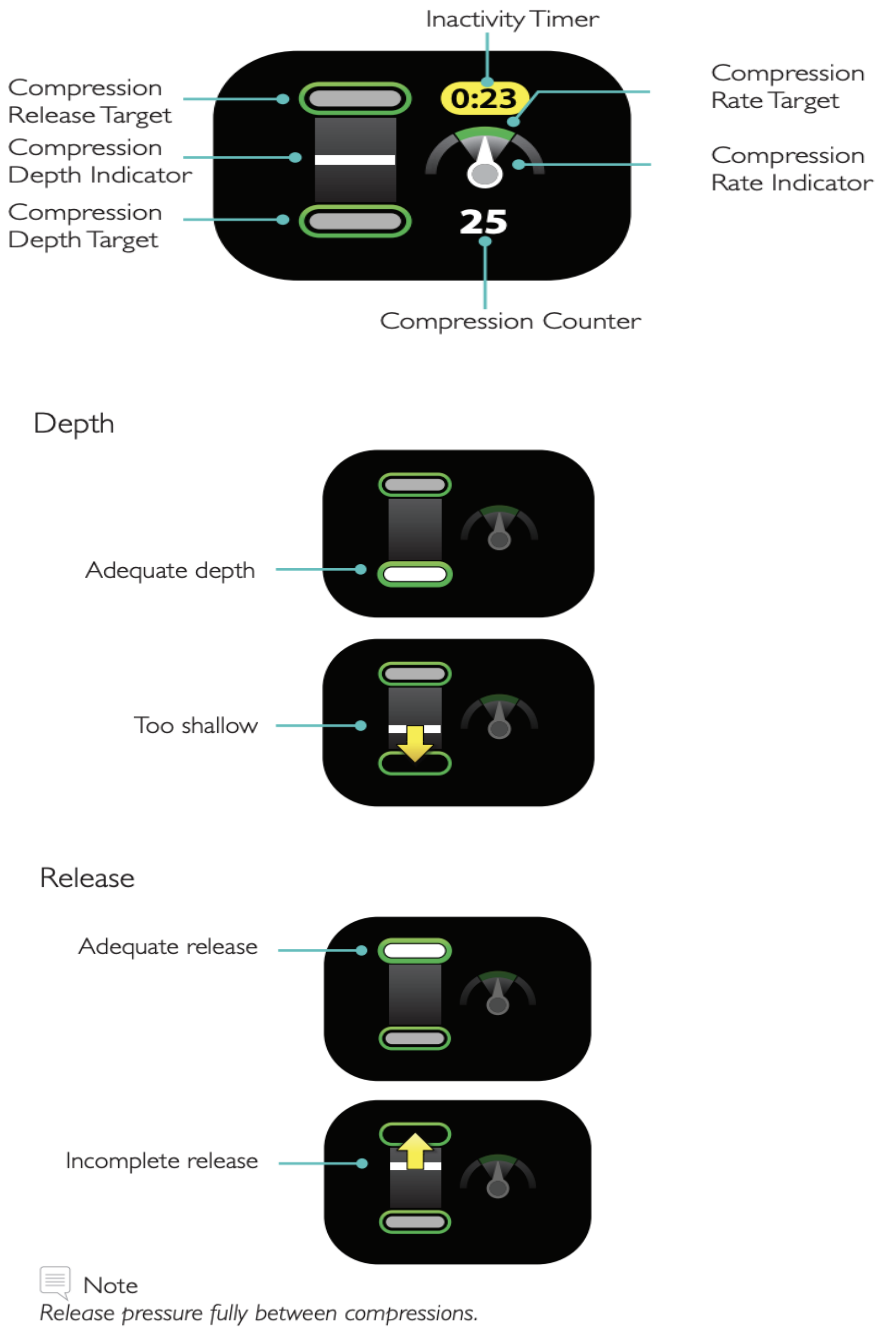


Figure 7. Details of CPRmeter 2 Real-time Provider Feedback (Laerdal, 2019)

This measurement was taken with the participant in the starting position before performing compressions. Participants got into the kneeling position next to the manikin, and placed the CPRmeter 2 in the center of the manikin chest, and positioned their hands on the CPR meter with their non-dominant hand resting on top of the other with their fingers from the top hand interlaced with those of the bottom hand. The participant was asked to hold that position while spine, hip and arm angles were assessed. Baseline heart rate, blood pressure, BORG 6-20, and blood lactate level were taken prior to compressions with a simple finger prick sample (Lactate Plus, Nova Biomedical Corp. Waltham, MA).

Participants were asked to perform CPR according to AHA guidelines (2" compression depth, 100-120 compressions per minute) for a total of 10 minutes (Kleinman et al., 2015). Participant heart rate was measured via heart rate monitor (Polar H1, Bethel Page, NY) and recorded at baseline, every 2 minutes, and immediately upon completion of compressions. BORG 6-20 RPE was obtained at baseline, every 2 minutes, and immediately upon completion of compressions. Participants were asked to point to their RPE on the Borg 6-20 RPE scale, which was also verbally verified by study staff. Regional fatigue using the BORG 6-20 RPE was obtained by staff at baseline, and immediately after compressions. Oxygen consumption was measured every 30 seconds during compressions via open circuit spirometry (ParvoMedics TrueOne 2400, Sandy, UT). The ParvoMedics TruOne 2400 system and software will utilize the oxygen consumption data collected every 30 seconds during the bout of CPR to determine absolute ($mL \bullet kg^{-1} \bullet min^{-1}$) consumption, and total energy expenditure (kcal). Two post- CPR blood lactate levels were taken. One immediately after compressions were completed, with the final lactate level taken 5 minutes after the test. Lactate was measured using a finger prick blood sample (Lactate Plus, Nova Biomedical Corp. Waltham, MA). Participants were instructed to perform compressions for as long as they can, and reminded that they should continue to perform CPR even if they feel the

quality of their CPR is declining. If a participant requested to stop prior to completing 10 minutes of CPR, total time performing CPR was recorded, CPR quality during that time period, and a final set of vitals, RPE, and blood lactate were collected, and recovery began. At the completion of the study, participants were asked to rest quietly in the seated position for a minimum of 10 minutes. The participant was only allowed to leave the Applied Physiology Lab if their heart rate had returned to pre-trial heart rate (within $\pm$ 10 BPM), and if the participant confirmed they were feeling well. If the participant complained of injury, or feeling unwell, a study physician/APP would evaluate the subject for further medical attention. Oxygen consumption data was printed and added to the participant's data file and saved as a *.csv file both on the ParvoMedics computer and uploaded to a RedCap database created specifically for this study. All other data was documented on a data sheet (Appendix C), which was also placed in the participant's data file and transcribed into the RedCap database. Photocopies of the hard copies of both the oxygen consumption data, and data sheet were also uploaded to the RedCap database.

3.5 PROTECTION OF SUBJECT INFORMATION

To protect private subject information, we assigned a unique study ID to each participant. A master list linked to the identifying data (subject names) to the study ID, which we kept on a secure network (i.e. Pitt Box, or the UPMC Y-Drive, or RedCap). Linking information was only accessible to authorized study staff. Files containing identifiers were stored in a locked filing cabinet in an office that is locked during non-business hours (i.e. the office is unlocked Monday-Friday 7:00 am – 6:00 pm and is otherwise locked).

3.6 DATA ANALYSES

Data is be stored in the form of both hard copy and stored electronically within the RedCap database. RedCap is a data capture platform available at University of Pittsburgh for all IRB-approved studies. RedCap allows users to create electronic data forms, as well as upload data in various formats (*.csv, *.xls, PDF, *.jpeg, etc). We performed statistical analyses using STATA 16 (College Station, Texas). Statistical significance was set *a priori* at $\alpha = 0.05$. Descriptive statistics (mean $\pm$ SD if normal distribution; median and IQR if non-normal distribution; and frequency (percentage) for categorical variables) was used to summarize participant characteristics and displayed in tabular and / or graphical form. All descriptive statistics were examined for skewness, kurtosis, and normality with transformation applied if necessary.

The outcome of CPR quality over time was assessed using four quality metrics: 1) compression rate, 2) compression depth, 3) compression force and 4) release force. Release force is an indicator of whether the provider is leaning on the manikin, which can prevent full chest recoil, and we utilized it as an additional CPR quality metric.

We conducted the following statistical analyses to examine the hypotheses of this investigation:

We performed two-way repeated measures ANOVA and Kruskal Wallis to assess CPR quality over time in the following groups: males versus females and CPR feedback versus no CPR feedback. Main effects of male versus female and CPR feedback versus no CPR feedback was determined, as well as the interaction terms between gender and time, and presence/absence of CPR feedback and time. If a main effect was significant, Tukey's Range Test was used for post-hoc analysis to identify which group means are significantly different.

We performed univariate analysis via correlations for continuous variables, Wilcoxon Ranked Sum Test for nominal predictors and t-tests for continuous outcomes to examine the association between four CPR quality metrics (compression rate, compression depth, compression force, and release force) and the following factors: time, age, gender, height, weight, BMI, $\dot{V}O_2$ Max, muscular strength, and muscular endurance. Any univariate analysis with a $p \leq 0.15$ was added to the final multivariate regression model (Bursac, Gauss, Williams, & Hosmer, 2008; Heinze, Wallisch, & Dunkler, 2018). We also compared differences between pre- and post-CPR blood lactate levels; pre- and post-CPR blood pressure; changes in $\dot{V}O_2$, global RPE and heart rate during CPR; and differences in regional RPE pre-CPR, and post-CPR.

3.6.1 Missing Data

Based on a review of similar studies, we believed it to be unlikely that participants would be unable to complete the full 10-minute bouts of CPR. Because of this, we chose to only use complete cases the two-way repeated measures ANOVA. In the case that a participant did not complete the full 10-minute bout, they we excluded from the primary analyses (two-way repeated measures ANOVA), and we performed two sample T-Test or Mann-Whitney U Tests to compare individual characteristics between subjects who can and cannot perform 10 minutes of CPR (e.g. compare BMI, age, height, weight, $\dot{V}O_2$ Max, muscular strength, and muscular endurance between groups). If a subject was missing less than 10% of data from a study visit, then we intended to use mean imputation to replace missing values. However, if more than 10% (N>3) of subjects are unable to complete the full 10-minute bout of CPR, or are missing more than 10% of study visit data, generalized linear modeling (GLM) will be used instead of two-way repeated measures ANOVA for primary analyses.

4.0 RESULTS

4.1.1 Participant Enrollment

Enrollment for this study occurred between April 2021- March 2022. We posted flyers throughout campus, sent emails to emergency medicine undergraduates and first- and second-year medical students, and registered the study with the Pitt+Me Study Registry. A total of 92 referrals came from the Pitt+Me Registry. Of those referrals, 18 were enrolled (Table 4). The remaining 8 enrollments came from study flyers, emails, and by word of mouth.

Table 4. Pitt+Me Screening & Enrollment Numbers

	Method	**Numbers**
Study Screenings	Online Screening	57
	Phone Screening	35
	Screening Failures	45
Referrals	Total Referrals	92
Enrolled from Pitt+Me	Total Enrolled	18

4.1.2 Participant Demographics

Due to the pandemic, recruitment proved to be challenging. We successfully enrolled the anticipated 15 females, however, we opted to close enrollment after only 11 of the anticipated 15 males were enrolled. Participants were 25 (IQR 22-37) years of age, 170.8 (SD 7.7) cm tall, weigh 69.5 (SD 13.7) kg, with a BMI of 23.6 (SD 3.3) kg/m^2, and 19.1% (SD 6/7) body fat. There was a

significant difference in height ($p<0.001$), weight ($p<0.001$), BMI ($p=0.004$), and body fat percent ($p=0.039$), between males and females. There was not a significant difference in age (Table 5).

Table 5. Participant Demographics

	Cohort	Males (N=11)	Females (N=15)	Mean Difference
Age (IQR)	25 (22-37)	24 (21-60)	25 (22-34)	6 (-8-20)
Race				
White/ Caucasian	23	10	13	-
Black /African American	1	-	1	-
Other	2	1	1	-
Ethnicity				
Non-Hispanic or Latinx	25	11	14	-
Height (cm) (SD)	170.8 (7.7)	176.4 (5.5)	166.6 (6.4)	9.7 (4.8-14.7)
Weight (kg) (SD)	69.5 (13.7)	80.2 (10.2)	61.6 (10.2)	18.6 (10.3-27)
BMI (kg/m^2) (SD)	23.6 (3.3)	25.8 (2)	22.2 (3.2)	3.6 (1.3-6)
Body Fat (%) (SD)	19.1 (6.7)	16 (6)	21.4 (6.4)	5.4 (0.3-10.5)

* Demographics are represented as mean and standard deviation when normal, and median and interquartile ranged when not normally distributed.

4.1.3 Participant Anthropometrics

Anthropometric measures were taken during the fitness assessment visit. Males were generally larger than female participants. There was a significant difference in arm span ($p<0.001$), arm length ($p=0.002$), upper arm length ($p=0.012$), shoulder-to-shoulder distance ($p<0.001$), chest circumference during inhalation ($p<0.001$) and exhalation ($p<0.001$), waist circumference ($p<0.001$), hip-to-shoulder distance ($p=0.002$), and upper leg length ($p=0.027$) (Table 6).

Table 6. Participant Anthropometrics

Measure (cm)	Cohort	Males	Females	Mean Difference
Arm Span	174 (168-177)	177 (176-186)	169 (165-173)	12.2 (6-18.5)

Arm Length	76 (74-79)	79 (75-83)	75 (74-77)	4.3 (1.7-7)
Upper Arm Length	37 (37-39)	39 (37-43)	37 (35-38)	2.7 (0.7-4.7)
Shoulder-to-shoulder	44.2 (41.5-46)	45 (44.8-48.5)	42 (38.7-43.5)	5.4 (2.8-8.1)
Chest (inhale)	88.8 (79-97)	98.9 (91-104)	80 (78-87)	15.8 (11.4-20.1)
Chest (exhale)	81 (72-88)	87.5 (85-97)	72 (71-80)	14.2 (8.2-20.2)
Waist	83 (72-93)	93 (87-100)	72 (69-85)	17.3 (9.2-25.3)
Hips	99 (94-105)	101 (97-105)	95 (86-108)	4.6 (-2.8-11.9)
Hip-to-shoulder	46 (43-51)	51 (46-54)	45 (42-46)	5.3 (2.1-8.4)
Upper Leg Length	46.1 (44-50)	49.5 (45-55)	45.5 (43-49)	4.3 (0.5-8)

* Measurements are reported in centimeters (cm) and represented as median and interquartile ranges.

4.1.4 Fitness Assessments

We measured muscular strength, endurance, and aerobic capacity.

4.1.4.1 Muscular Strength

We used grip strength to assess muscular strength. Male participants had a significantly higher grip strength (i.e. higher muscular strength) than female participants ($p<0.001$). Strength is reported in kilograms and represented as median and interquartile range (Table 7).

Table 7. Muscular Strength Assessment

	Cohort	**Males**	**Females**	**Mean Difference**
Strength (kg)	37 (29-47)	49 (42-73)	30 (25-34)	26 (17-35)

4.1.4.2 Muscular Endurance

Muscular endurance was assessed using the push-up test. Participants performed two sets of push-ups, one set in the standard position, and the other in the modified position (on the knees). The order of push-up positioning was counter-balanced. Both males and females performed more push-ups in the modified position than in the standard position. Regardless of positioning, males performed significantly more push-ups (i.e. had more muscular endurance) than females (modified, p=0.006; standard, p=0.002). Push-up performance is represented as median and interquartile range (Table 8).

Table 8. Push-up Assessments

	Cohort	**Males**	**Females**	**Mean Difference**
Standard Position	17 (8-33)	33 (20-45)	10 (4-18)	19 (8-30)
Modified Position	26 (21-36)	36 (26-55)	24 (16-26)	18 (6-30)

4.1.4.3 $\dot{V}O_2$ Max

$\dot{V}O_2$ Max was assessed using the Modified Bruce Treadmill Protocol. Refer to section *3.4.5 Maximal Exercise Treadmill Test* for $\dot{V}O_2$ Max criteria. All participants met $\dot{V}O_2$ Max criteria. Males had a higher aerobic capacity compared to female participants, but the difference was not significant. $\dot{V}O_2$ Max is represented as median and interquartile range (Table 9).

Table 9. $\dot{V}O_2$ Max Assessments

	Cohort	**Males**	**Females**	**Mean Difference**
$\dot{V}O_2$ Max (ml/kg/min)	39.1 (31-42.2)	42 (27.4-52)	33.4 (31-41)	5.2 (-3-13.4)

4.1.5 CPR Quality

The Laerdal CPR meter provided information on compression rate, compression depth, and release force, therefore, the compression force needed to be calculated. Compression force was calculated using Hooke's law based on the product information that the spring in the manikin required 50kg of force to compress the spring by 50mm (Figure 8). Compression quality variables are represented as median and interquartile range (Table 10). Minute-by-minute CPR quality metrics by gender and feedback status are represented as medians in figures (Figure 9).

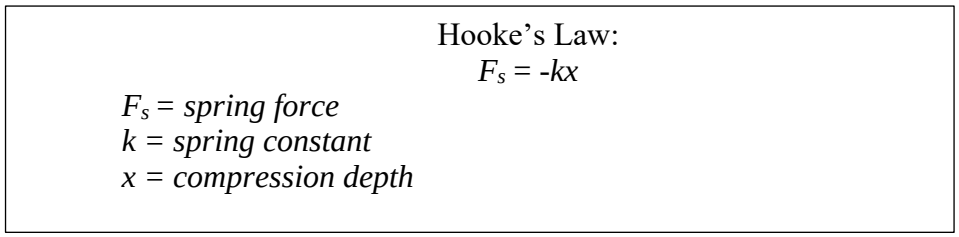


Figure 8. Hooke's Law

There were three females who were unable to perform the full 10-minutes of CPR and were excluded from analyses involving CPR quality metrics. There were an additional two participants, one male and one female, who performed compressions for the full duration, but compressions were so shallow that they were not reliably detected by the Laerdal CPR Meter. They too were excluded from CPR quality metric analyses. None of the compression quality variables met the normality or equal variance assumptions of ANOVA and therefore Kruskal Wallis was also used to compare each variable between groups. ANOVA results agreed with Kruskal Wallis results for each CPR quality variable. Compression rate ($p=0.038$), depth ($p<0.001$), force ($p<0.001$) and release force ($p<0.001$) differed significantly between males and females, with males performing compressions at a faster rate, with more depth, and with more compression and release force than females. On average, males performed approximately 7 more compressions per minute, that were 6mm deeper, with approximately 6.2kg more downward compression force, and 3.6kg more

release force. A higher release force indicates that the participant is leaning, suggesting that female participants leaned significantly less on the manikin than male participants.

Compression depth ($p<0.001$), and force ($p<0.001$), differed between episodes with and without feedback. Compressions were applied with approximately 4.4kg more force and were 4mm deeper when feedback was present.

There were interaction effects between gender and feedback for compression depth ($F(1,456) = 4.63$; $p=0.032$), release force ($F(1, 456) = 5.25$; $p=0.022$) and compression force ($F(1,456) = 4.63$; $p=0.032$). The interaction between gender and feedback accounted for 15% of variation in compression depth, 24% of variation in release force, and 15% in compression force. With compression depth and force improving for female participants when feedback was present. Rate did not differ based on time or feedback status, nor was there an interaction effect.

Table 10. CPR Quality Summaries

	Cohort WFB	**Cohort WOFB**	**Males WFB**	**Males WOFB**	**Females WFB**	**Females WOFB**
Rate (Compressions per minute)	112 (94-122)	112 (95-124)	111 (92-128)	114 (95-127)	112 (98-118)	112 (95-120)
Depth (mm)	36 (27-41)	30 (21-39)	37 (33-42)	38 (25-41)	35 (23-40)	26 (20-32)
Force (kg)	-36.5 (27.2-41.2)	-30.1 (21.4-39.3)	-37 (33-42.2)	-38.1 (25-40.7)	-35 (23.3-39.9)	-26 (19.8-32)
Release Force (kg)	2.1 (1.2-4.8)	2.4 (1.3-4.4)	3.8 (2-7.7)	4.3 (2.7-10)	1.4 (0.9-2.2)	1.6 (0.8-2.4)

*WFB = CPR with feedback / WOFB = CPR without feedback

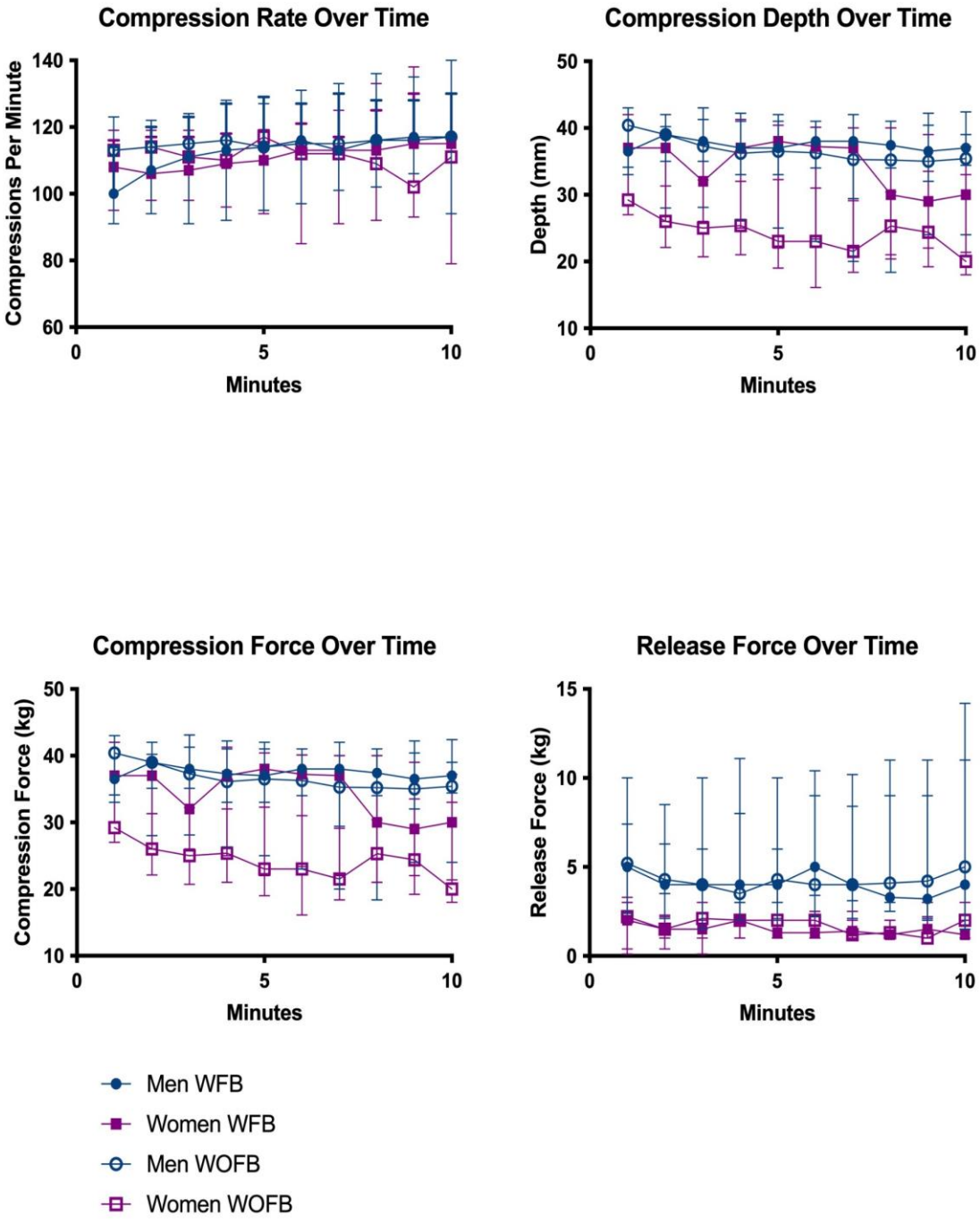


Figure 9. Minute-by-Minute CPR Quality Metrics

4.1.6 CPR Descriptive

4.1.6.1 Angles Relative to Manikin

Three body angles relative to the manikin were measured before each CPR session. The measured angles were arm-to-spine, spine-to-hips, and arm-to-manikin (Figure 10).

Figure 10. Angle Measurements Relative to Manikin

There was not a significant difference of any angle of the body relative to the manikin between males and females regardless of CPR feedback status. Measurements are represented in degrees and reported as median and interquartile range (Table 11).

Table 11. Body Angles Relative to Manikin

	Cohort	Males	Females	Mean Difference
With Feedback				
Arm-to-spine	76 (71-81)	79 (74-82)	75 (66-80)	8 (-6 to 22)
Spine-to-hips	111 (104-117)	114 (104-121)	106 (104-117)	5 (-6 to15)
Arm-to-manikin	70 (61-75)	74 (63-81)	66 (61-74)	3 (-7 to14)
Without Feedback				
Arm-to-spine	78 (72-82)	76 (74-79)	80 (71-83)	1 (-9 to 7)
Spine-to-hips	114 (110-118)	114 (105-132)	114 (110-118)	2 (-8 to 12)
Arm-to-manikin	71 (64-76)	68 (60-76)	71 (64-74)	1 (-9 to 6)

4.1.7 Physiological Measurements During CPR

4.1.7.1 Lactate

Lactate levels were not normally distributed, so Wilcoxon signed-rank tests were performed to compare lactate levels between genders and feedback status. Wilcoxon rank-sum tests were performed to compare lactate levels by pre- and post-CPR lactate values. Values are reported as median and interquartile ranges. Mean differences are reported to allow for further conceptualization of differences (Figure 11, Table 12). Males had significantly higher baseline lactate levels both with and without CPR feedback. Males had baseline lactate levels that were a mean of 1.9 mmol/L higher (p=0.059; IQR 0.1-3.8) when feedback was present, and 0.8 mmol/L higher (p=0.005; 95% IQR 0.2-1.4) without feedback. Immediate and 5-minutes post-CPR lactate levels did not differ between males and females regardless of feedback status.

Immediately after CPR, lactate levels were a mean of 2.3 mmol/L ($p<0.001$; 95% CI 0.9-3.7) higher than baseline with feedback, and 1.8 mmol/L ($p<0.001$; 95% CI 1-2.6) higher than baseline without feedback. Compared to baseline values, 5-minutes post-CPR lactate levels were a mean of 0.8 mmol/L ($p=0.004$; 95% CI 2.3-0.7), higher with feedback and 2.1 mmol/L ($p<0.001$; 95% CI 0.9- 3.3) higher without feedback.

Table 12. Pre & Post-CPR Lactate Values

	Cohort	**Males**	**Females**	**Mean Difference**
With Feedback				
Baseline (IQR)	1.3 (1.1-2.2)	2.1 (1.1-3.2)	1.3 (1-1.6)	1.9 (0.1-3.8)
Post-CPR (IQR)	3.6 (2.4-4.6)	4.4 (4.2-6.5)	3 (2.3-4.6)	1.4 (-1-4)
5-minutes Post-CPR (IQR)	2.7 (1.8-3)	2.8 (2.3-3.4)	2.6 (1.7-3)	0.8 (-1-2.5)
Without Feedback				
Baseline (IQR)	1.3 (1-1.8)	2 (1.5-2.2)	1.1 (1-1.4)	0.8 (0.2-1.4)
Post-CPR (IQR)	2.9 (1.7-4.3)	3.5 (2.8-4.9)	2.4 (1.5-3.4)	0.8 (-1-2.6)
5-minutes Post-CPR (IQR)	3.2 (2-4.2)	3.4 (2.3-4.3)	3.2 (2-3.3)	1.6 (-1.2-3.6)

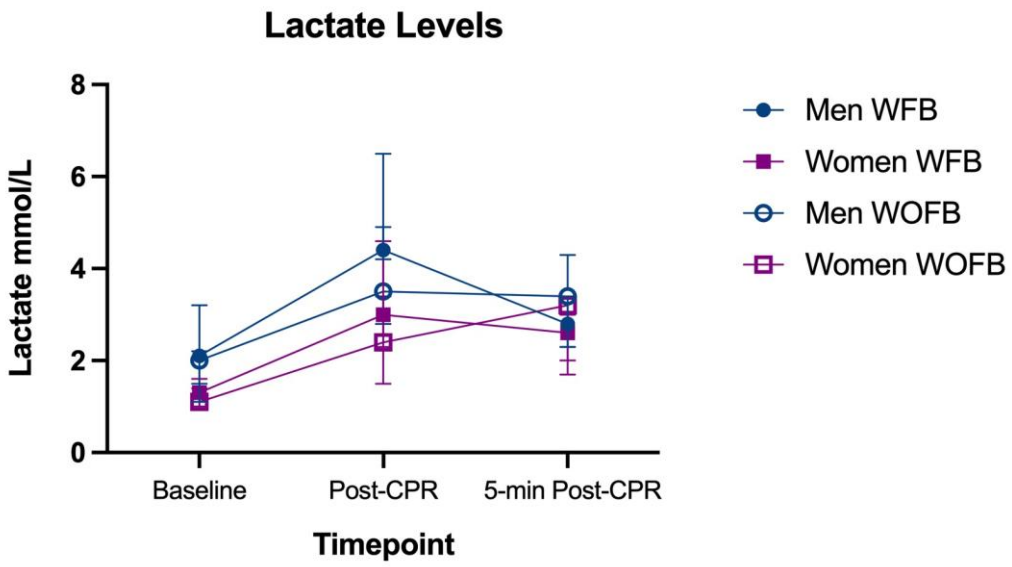


Figure 11. Median Lactate Levels Over Time

4.1.7.2 Blood Pressure

Prior to CPR sessions with feedback, males had a resting systolic blood pressure (SBP) that was on average 9 mmHg higher than females (p=0.015, 95% CI 2-15). Similarly, males had a significantly higher SBP post-CPR with feedback, being an average of 13 mmHg higher than females (p=0.004, 95% CI 5-21). Diastolic blood pressure (DBP) did not differ at any point between males and females regardless of feedback status.

Post-CPR SBPs were significantly higher with and without feedback. SBP was an average of 8 mmHg higher than baseline with feedback (p<0.001; 95% CI 12-5), and 8 mmHg higher than baseline without feedback (p=0.001; 95% CI 12-3). DBPs did not increase significantly after CPR, nor was there a significant difference in SBPs or DBPs based on feedback or gender. Graphs represent pre-and post-CPR blood pressures as median and interquartile range (Figure 12).

Table 13. Pre & Post- CPR Blood Pressures (mmHg)

	Cohort	Males	Females	Mean Difference (95% CI)
With Feedback				
Baseline SBP (SD)	122 (±9)	127 (± 8)	118 (± 8)	9 (2-15)
Baseline DBP (SD)	71 (± 6)	73 (± 6)	69 (± 6)	4 (-1-9)
Post-CPR SBP (IQR)	128 (123-138)	138 (131-145)	125 (123-128)	13 (5-21)
Post-CPR DBP (SD)	72 (±7)	75 (± 6)	71 (± 8)	4 (-1-10)
Without Feedback				
Baseline SBP (SD)	123 (± 8)	125 (±7)	122 (±8)	3 (-3-9)
Baseline DBP (SD)	72 (± 8)	72 (± 7)	72 (± 9)	-1 (-8-6)
Post-CPR SBP (IQR)	130 (120-139)	131 (122-144)	126 (119-137)	7 (-3-17)
Post-CPR DBP (SD)	69 (± 10)	72 (± 11)	67 (± 9)	5 (-2-13)

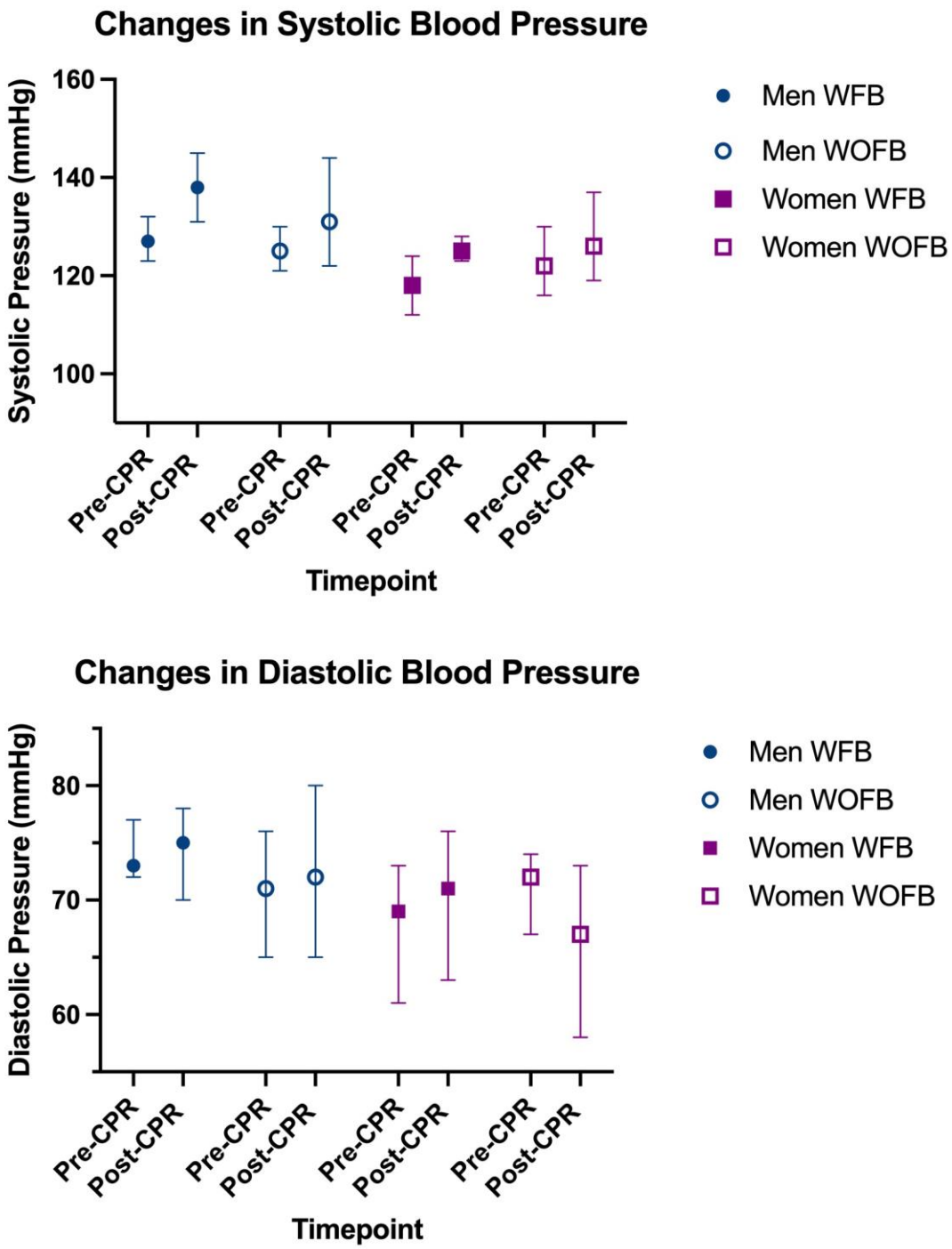


Figure 12. Pre & Post CPR Blood Pressures

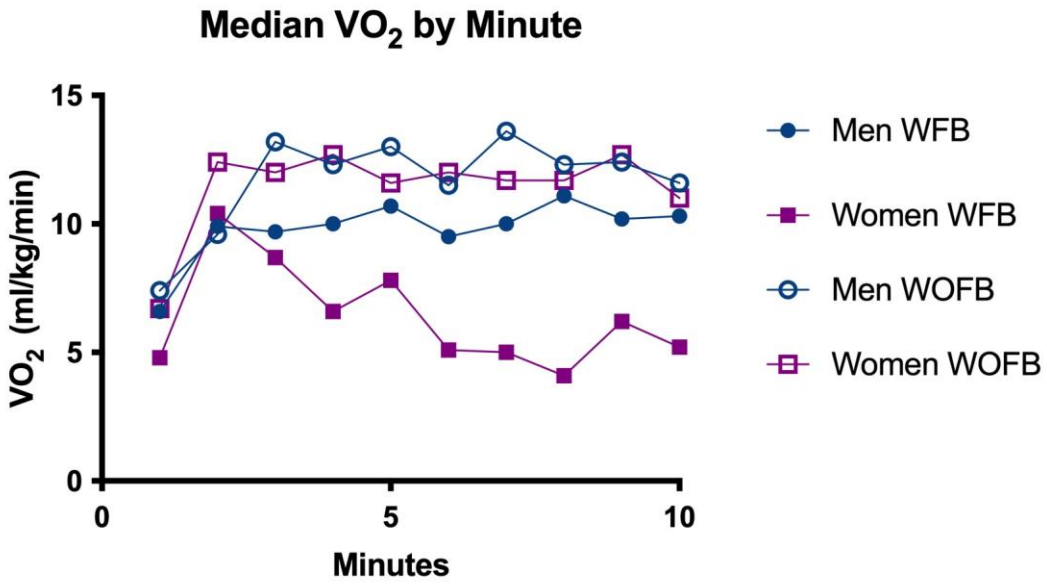
4.1.7.3 $\dot{V}O_2$ During CPR

There was not a significant difference in $\dot{V}O_2$ peak between males and females regardless of feedback status. Peak $\dot{V}O_2$ values are reported as mean and standard deviation (Table 14).

Table 14. $\dot{V}O_2$ Peak During CPR

	Cohort	Males	Females	Mean Difference (95% CI)
With Feedback				
$\dot{V}O_2$ (SD) ml/kg/min	12.7 (± 5.4)	13.7 (± 5.8)	12.1 (± 5.1)	1.6 (-2.9 to 6)
Without Feedback				
$\dot{V}O_2$ (SD) ml/kg/min	14.4 (± 5.3)	15.7 (±6.3)	13.5 (± 4.4)	2.1 (-2.2 to 6.5)

Throughout the bouts of CPR median $\dot{V}O_2$ remained relatively stable for all groups except women performing CPR with feedback, which steadily declined. However, median minute-by-minute $\dot{V}O_2$ did not significantly differ between any group (Figure 13). Median minute-by-minute $\dot{V}O_2$ are represented graphically in Figure 13 with and without error bars for better visualization.



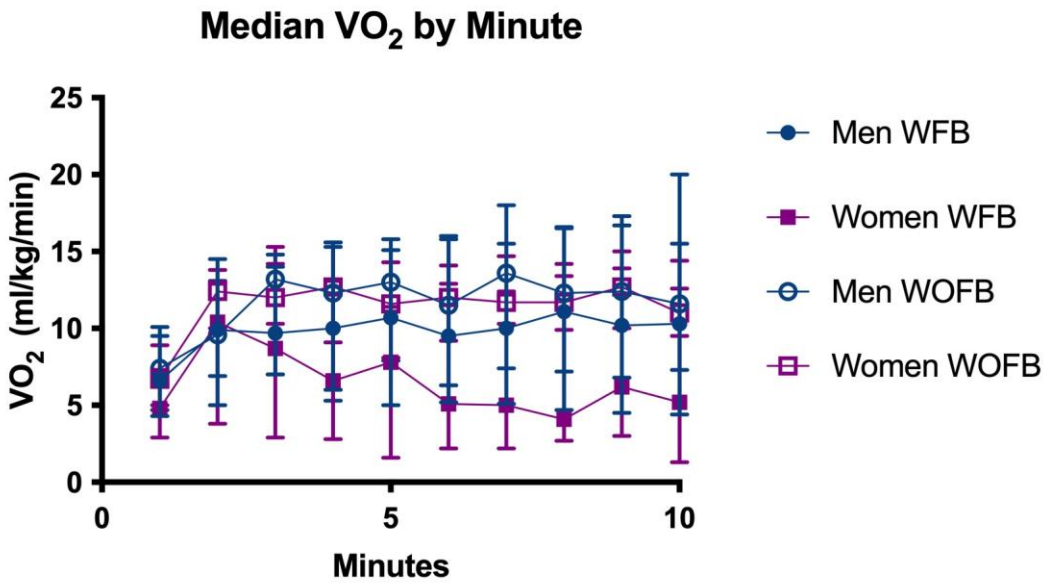


Figure 13. Median $\dot{V}O_2$ by Minute

4.1.7.4 Heart Rate During CPR

There was not a significant difference in peak heart rate (HR) between males and females regardless of feedback status. HR values are reported as mean and standard deviation (Table 15).

Table 15. Peak Heart Rate During CPR

	Cohort	Males	Females	Mean Difference (95% CI)
With Feedback				
HR (BPM)	138 (± 19)	133 (± 17)	140 (± 21)	-6 (-22 to 10)
Without Feedback				
HR (BPM)	133 (± 21)	127 (± 21)	138 (± 20)	-12 (-29 to 5)

HR trends were similar between males and females and feedback status. Minute-by-minute HRs were generally lower for males performing CPR without feedback however, this difference

was not statistically significant (Figure 14). Heart rate over time is represented graphically in Figure 14 with and without error bars for better visualization.

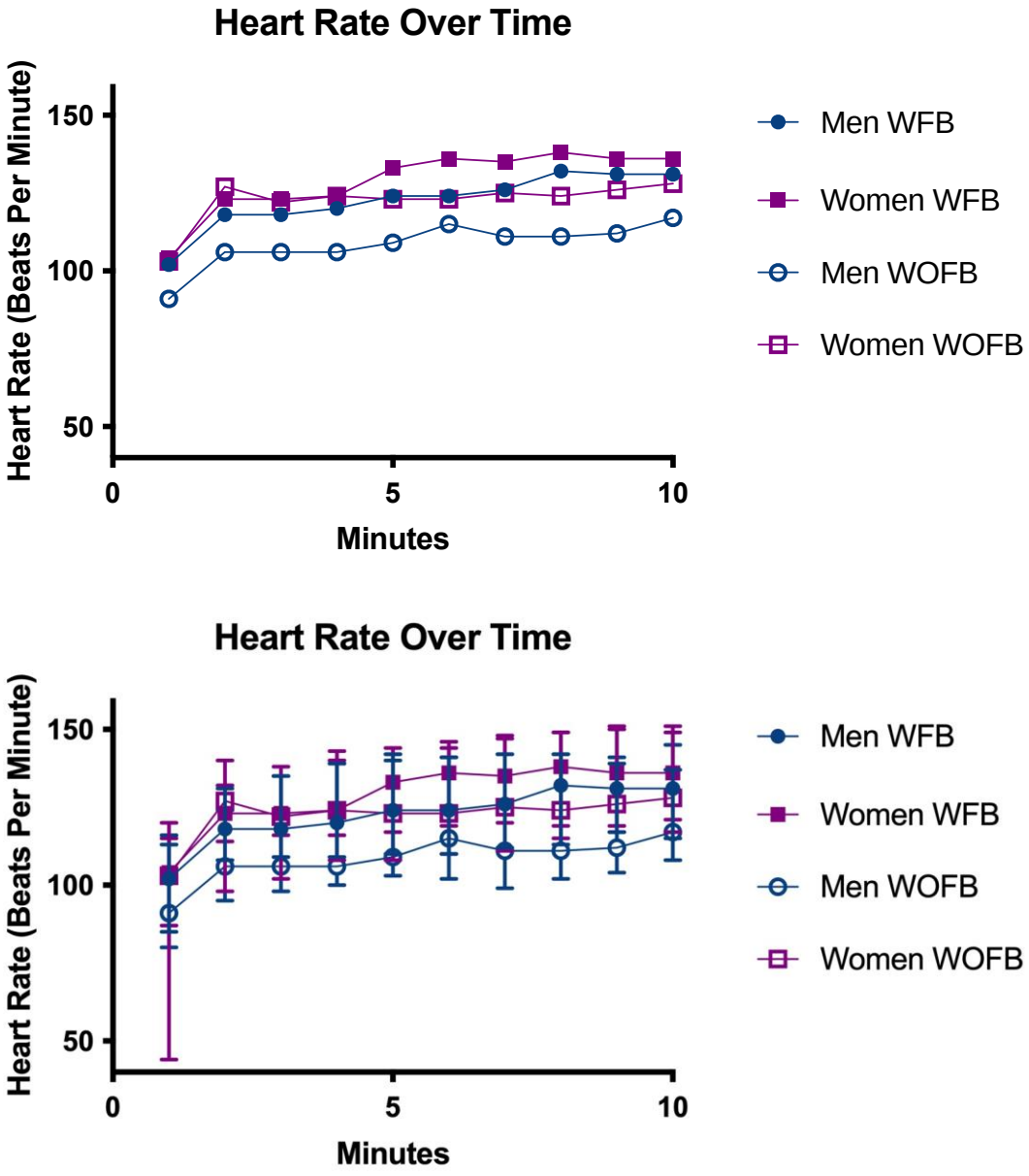


Figure 14. Median Heart Rate by Minute

4.1.8 Perceived Exertion

RPE significantly increased from baseline both with ($p<0.001$; Mean Difference 8; 95% CI 10-7) and without ($p<0.001$; Mean Difference 8; 95% CI 9-7) CPR feedback (Table 16, Figure 15). Global RPE immediately post-CPR only differed between males and females in the presence of feedback ($p=0.028$; Mean Difference 2; 95% CI 5-1). Otherwise, there was not a significant difference in global RPE between males and females.

Regional RPE after CPR also changed significantly from baseline. With CPR feedback, fatigue in the low back ($p<0.001$, Mean Difference 3; 95% CI 4-2), triceps ($p<0.001$; Mean Difference 6; 95% CI 7-4), abdominal muscles ($p<0.001$; Mean Difference 2; 95% CI 3-1), and knees ($p<0.001$; Mean Difference 3; 95% CI 4-2) all increased significantly after CPR. Similarly, fatigue in the low back ($p<0.001$; Mean Difference 3; 95% CI 4-2), triceps ($p<0.001$; Mean Difference 6; 95% CI 7-4), abdominal muscles ($p<0.001$; Mean Difference 2; 95% CI 3-1), and knees ($p<0.001$; Mean Difference 3; 95% CI 3-1) all increased from baseline. Pre- and Post-CPR regional RPEs did not differ between males and females regardless of feedback status. RPE was not different based on feedback status. RPEs are reported in graphs and tables as median and interquartile ranges (Table 16, Figure 15, Figure 16). Median and interquartile ranges for regional RPE were identical both with and without feedback, so only one graph has been used to represent the data.

Table 16. Global & Regional Ratings of Perceived Exertion With Feedback

	Cohort	**Males**	**Females**	**Mean Difference**
With Feedback				
Pre-CPR Global	6 (6-7)	6 (6-7)	6 (6-7)	1 (1-2)
Post-CPR Global	15 (13-17)	14 (13-15)	16 (14-19)	-2 (-5 to 1)

Pre-CPR Low Back	6 (6-7)	6 (6-7)	6 (6-7)	-1 (-2 to 1)
Post-CPR Low Back	9 (7-12)	8 (6-12)	9 (7-12)	-1 (-3 to 2)
Pre-CPR Triceps	6 (6-7)	6 (6-7)	6 (6-7)	0 (-1 to 1)
Post-CPR Triceps	13 (9-15)	15 (9-15)	11 (8-16)	2 (-2 to 5)
Pre-CPR Abdominal	6 (6-7)	6 (6-7)	6 (6-6)	0 (-1-1)
Post-CPR Abdominal	8 (7-10)	8 (7-8)	9 (6-11)	-1 (-3 to 1)
Pre-CPR Knees	6 (6-7)	6 (6-7)	6 (6-7)	0 (-1 to 1)
Post-CPR Knees	8 (7-11)	8 (7-11)	9 (6-11)	-1 (-3 to 1)
Without Feedback				
Pre-CPR Global	6 (6-7)	6 (6-7)	6 (6-7)	1 (1-2)
Post-CPR Global	14 (13-17)	14 (13-16)	16 (13-18)	-1 (-4 to 2)
Pre-CPR Low Back	6 (6-7)	6 (6-7)	6 (6-7)	0 (-1 to 1)
Post-CPR Low Back	9 (7-12)	8 (6-12)	9 (7-12)	-1 (-3 to 2)
Pre-CPR Triceps	6 (6-7)	6 (6-7)	6 (6-7)	0 (-1 to 1)
Post-CPR Triceps	13 (9-15)	15 (9-15)	11 (8-16)	2 (-2 to 5)
Pre-CPR Abdominal	6 (6-7)	6 (6-7)	6 (6-7)	0 (-1 to 1)
Post-CPR Abdominal	8 (7-10)	8 (7-8)	9 (6-11)	-1 (-3 to 1)
Pre-CPR Knees	6 (6-7)	6 (6-7)	6 (6-7)	0 (-1 to 1)
Post-CPR Knees	8 (7-11)	8 (7-11)	9 (6-11)	-1 (-3 to 1)

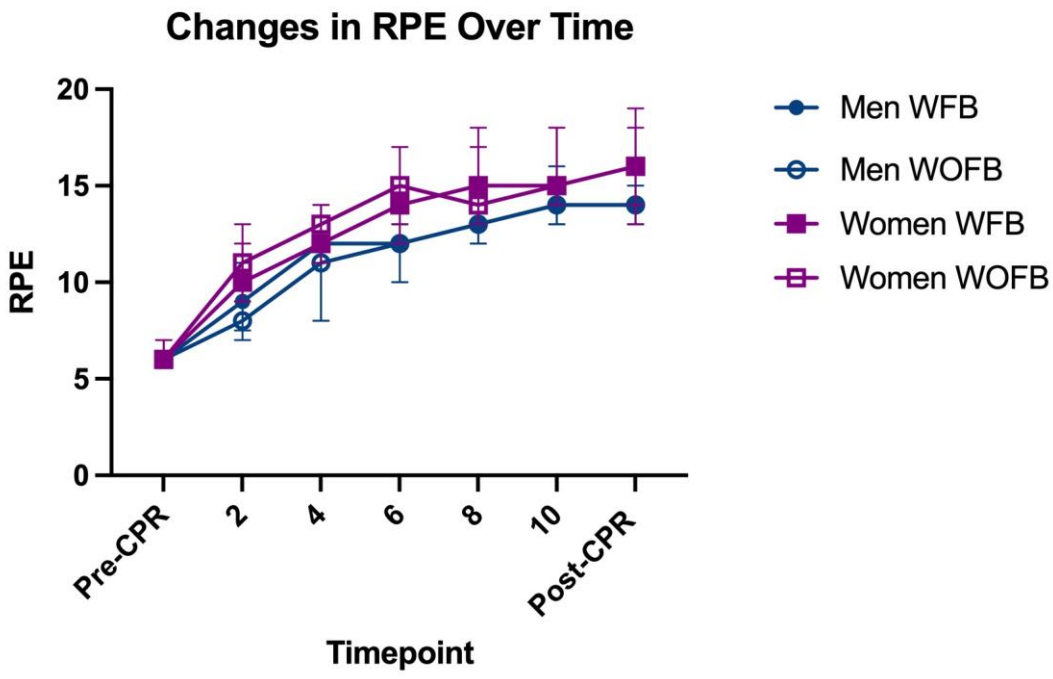


Figure 15. Changes in Global RPE Over Time

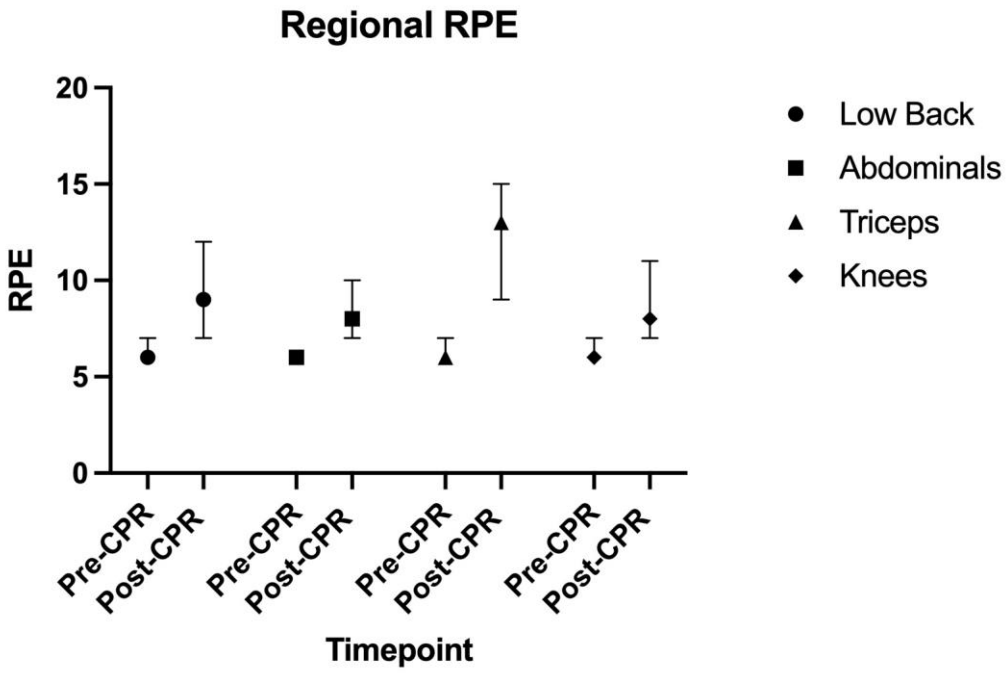


Figure 16. Changes in Regional RPE (For Entire Cohort)

4.1.8.1 Respiratory Rate & Perceived Exertion

Increased respiratory rate is an indicator of increased work effort. Despite females having a higher Global RPE immediately post-CPR compared to males in the presence of feedback (p=0.028; Mean Difference 2; 95% CI 5-1), respiratory rate was not significantly different between males and females regardless of CPR quality feedback (Table 17; Figure 17). Refer to Table 16 for a complete table of global and regional RPEs. Increased respirations may be an influencing factor in an individual's RPE. Respiration rate over time is shown graphically both with and without error bars for visualization purposes.

Table 17. Respirations Per Minute

	Cohort	Males	Females	Mean Difference (95% CI)
With Feedback				
Breaths Per Minute (IQR)	25 (18-29)	25 (20-30)	25 (18-30)	2 (-1-4)
Global RPE	15 (13-17)	14 (13-15)	16 (14-19)	-2 (-5 to 1)
Without Feedback				
Breaths Per Minute (IQR)	23 (20-29)	23 (20-27)	25 (19-28)	1 (-1-3)
Global RPE	14 (13-17)	14 (13-16)	16 (13-18)	-1 (-4 to 2)

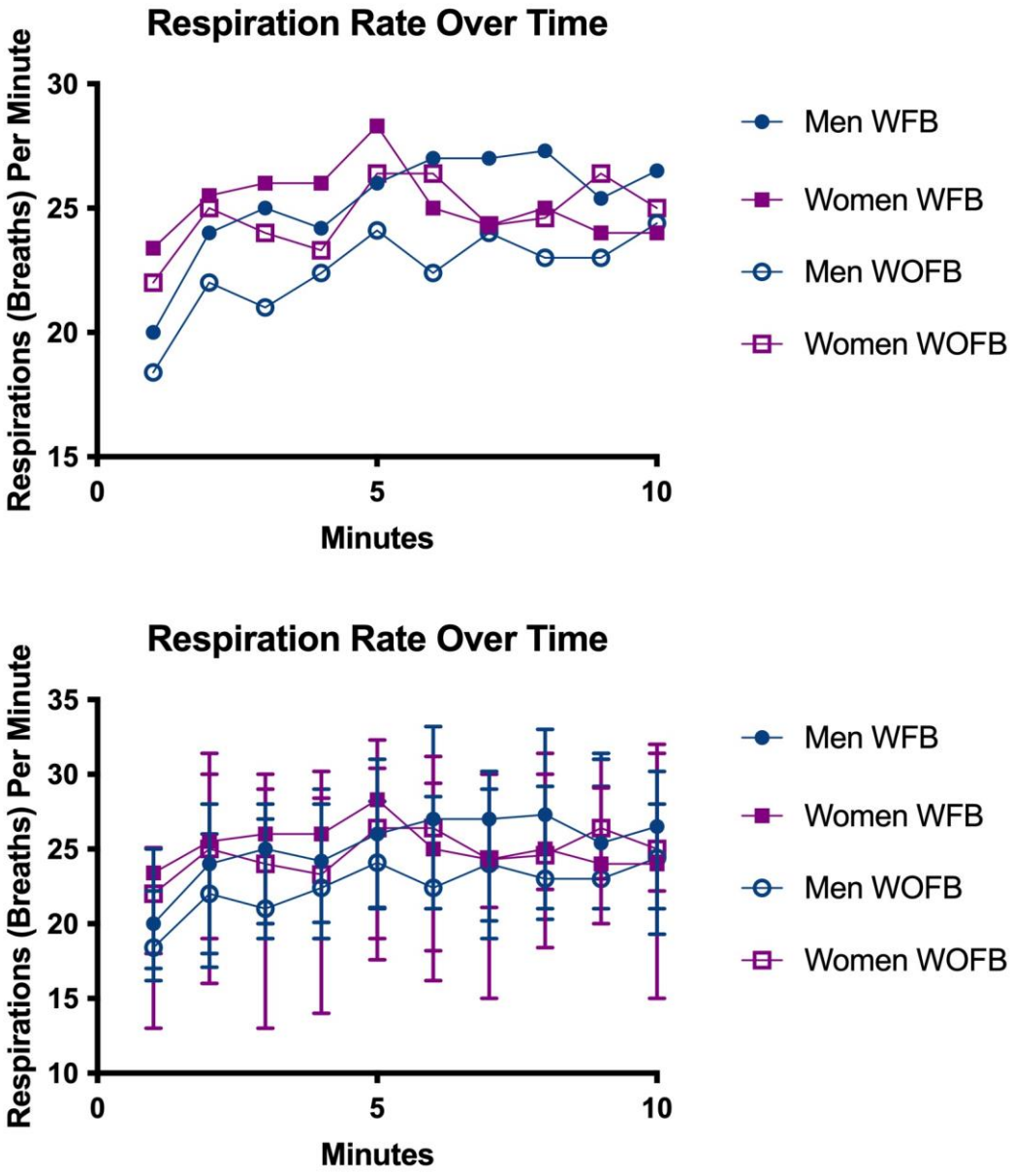


Figure 17. Median Respirations (Breaths) Per Minute

4.1.8.2 Heart Rate & Perceived Exertion

Relationship between heart rate and perceived exertion were visually assessed. Generally, RPE increased proportionately to heart rate over time, with males without feedback having slightly

lower heart rates and RPEs compared to other groups (Figure 18). However, as previous results show, these differences were not statistically significant.

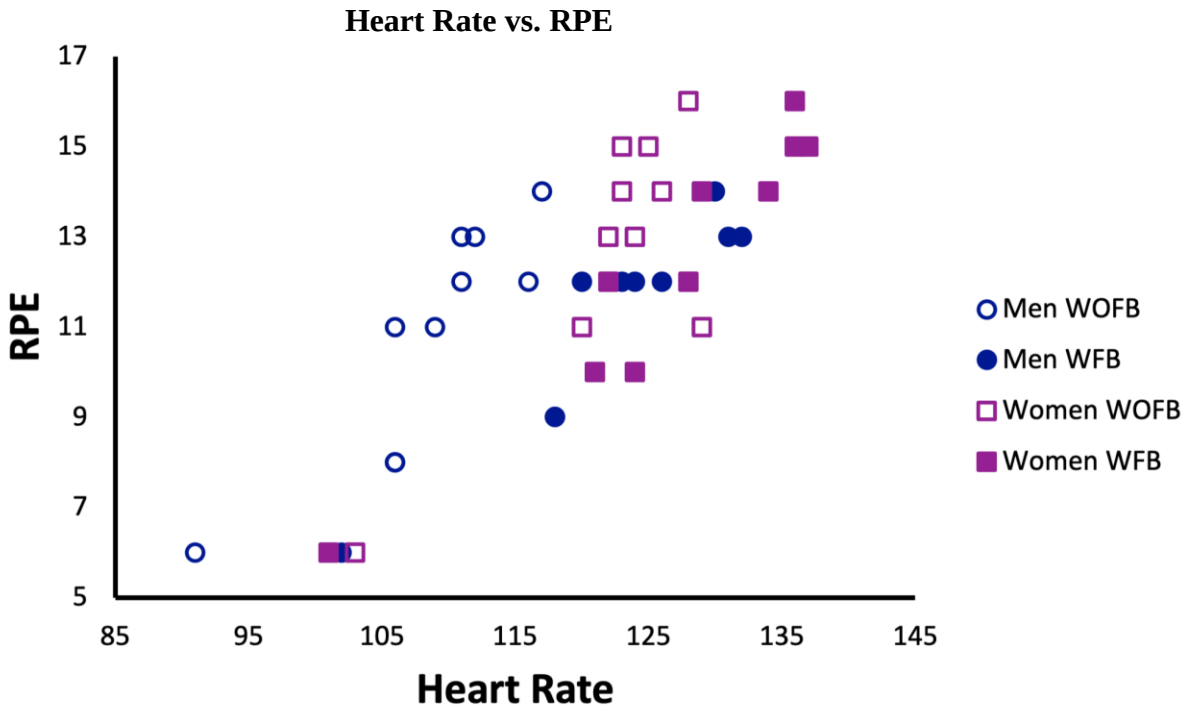


Figure 18. Heart Rate & RPE vs. Time

4.1.8.3 Lactate & Perceived Exertion

The relationship between Lactate and RPE over time was also visually assessed. Lactate and RPE increased proportionately from baseline over time. Generally, men and women followed a similar trend, but men had a slightly higher starting Lactate, and women had a slightly higher post-CPR RPE. Again, the differences in post-CPR Lactate did not differ between men and women, or based on CPR feedback presence.

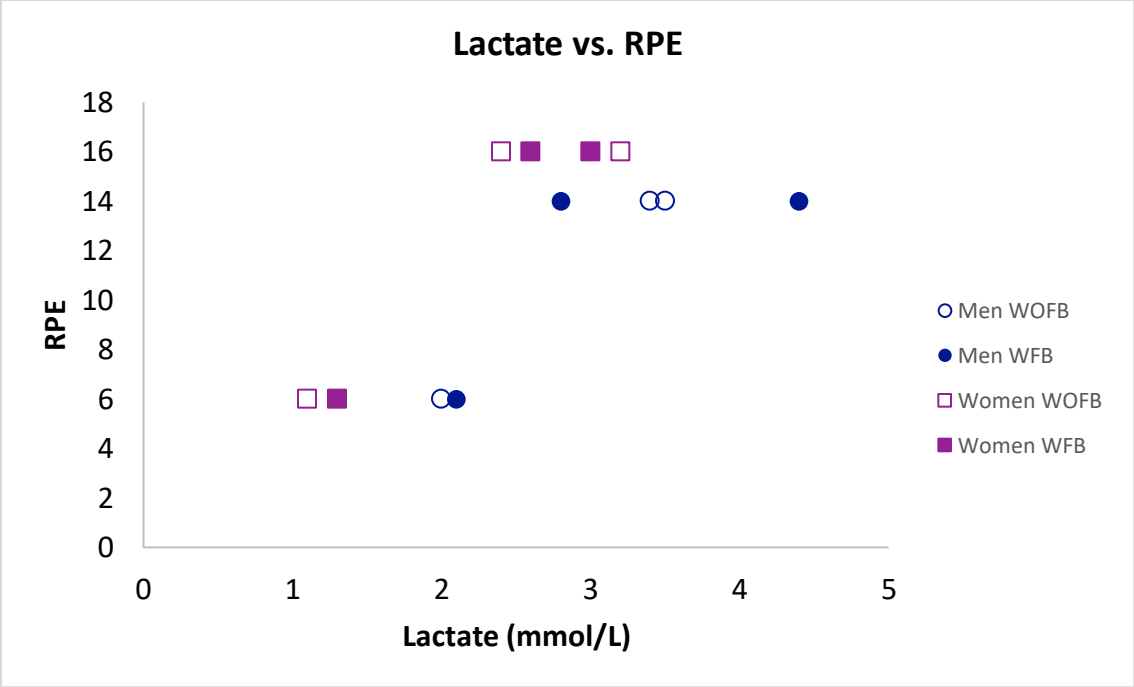


Figure 19. Lactate & Perceived Exertion vs. Time

4.1.9 Brief Pain Inventory

Within the first five minutes after a bout of CPR, participants were asked to mark regions on the image in which they felt pain or fatigue on the Brief Pain Inventory Scale. Figures represent areas where participants reported pain while performing CPR with and without feedback. Values represent the number and percentage of males and females who reported pain in that region, and the mean difference between genders with a 95% confidence interval (Figures 13-16). Females commonly reported pain in their biceps, knees, triceps, and low back regardless of feedback presence. Slightly more females reported pain in their right latissimus dorsi in the absence of feedback. Males reported pain in different areas based on feedback presence. Males commonly reported pain in their biceps and triceps regardless of feedback but also reported pain in the wrists

in the presence of feedback, and pain in their knees, low back, and latissimus dorsi in the absence of feedback (Figures 13-16).

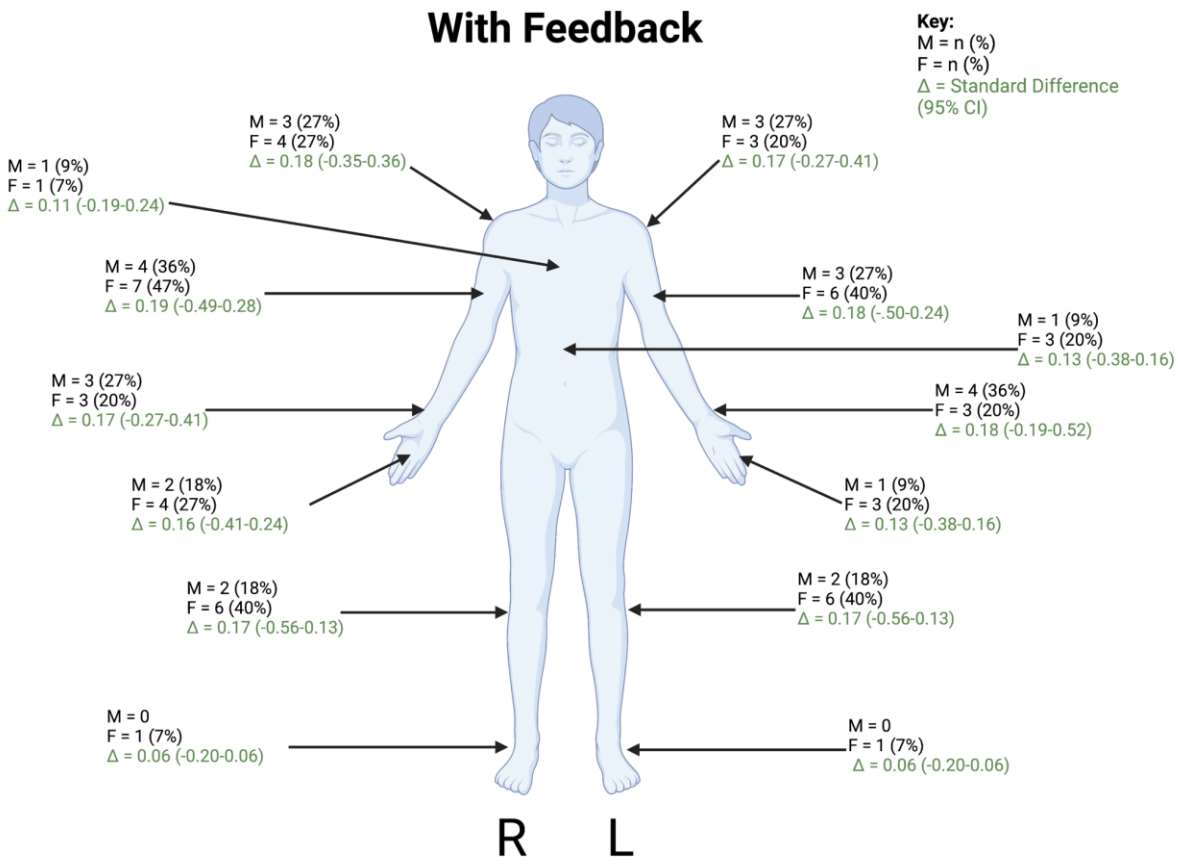


Figure 20. Brief Pain Inventory- Front With Feedback

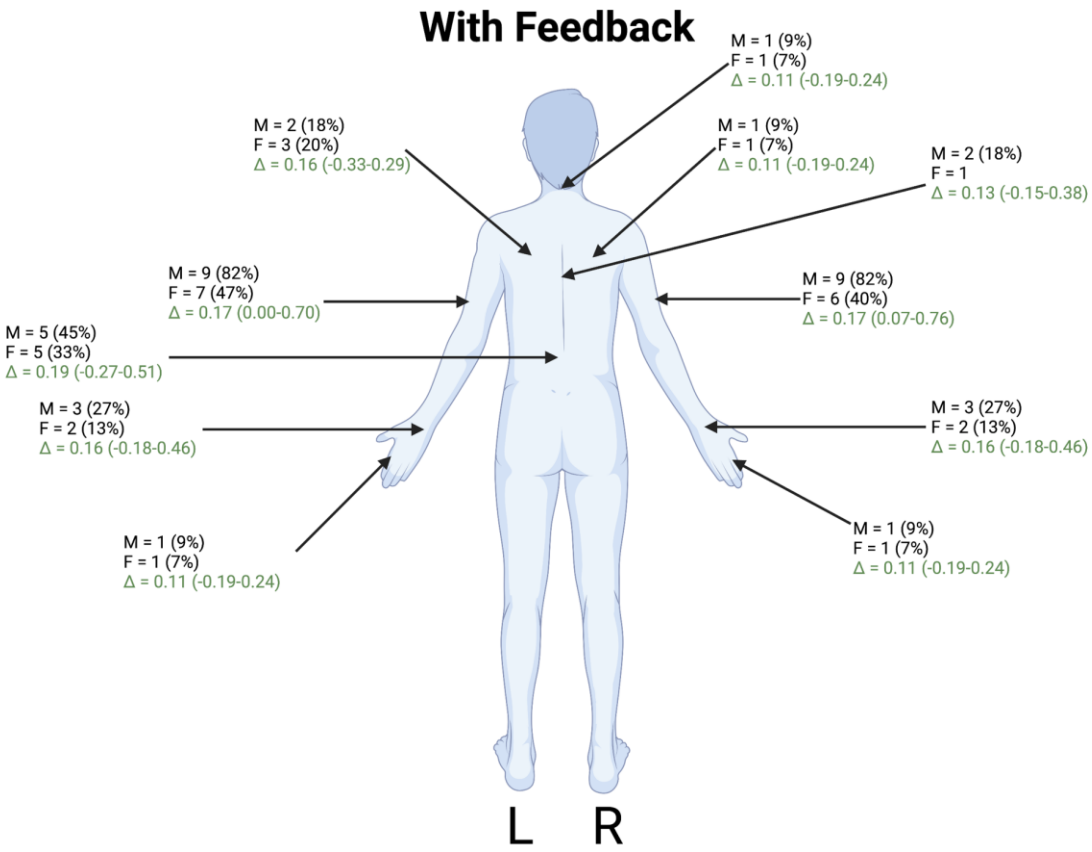


Figure 21. Brief Pain Inventory- Back With Feedback

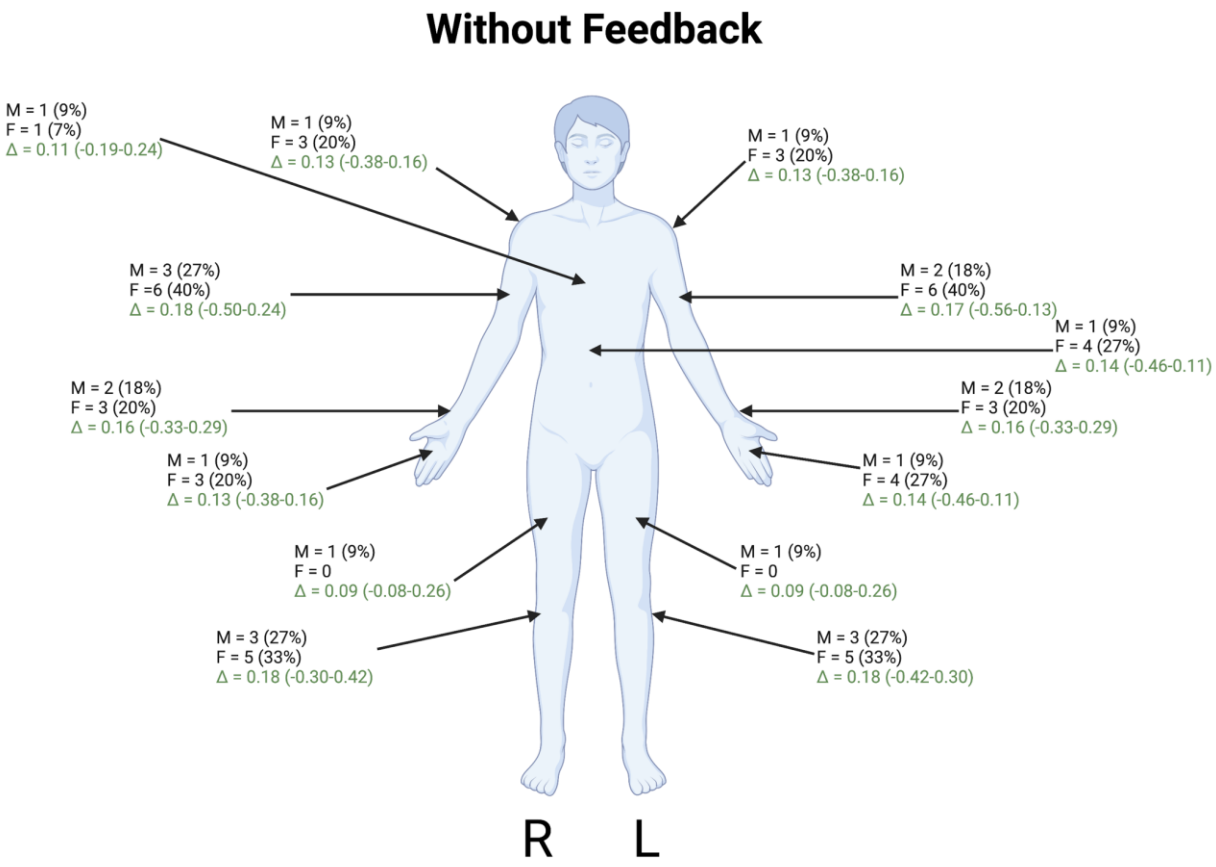


Figure 22. Brief Pain Inventory- Front Without Feedback

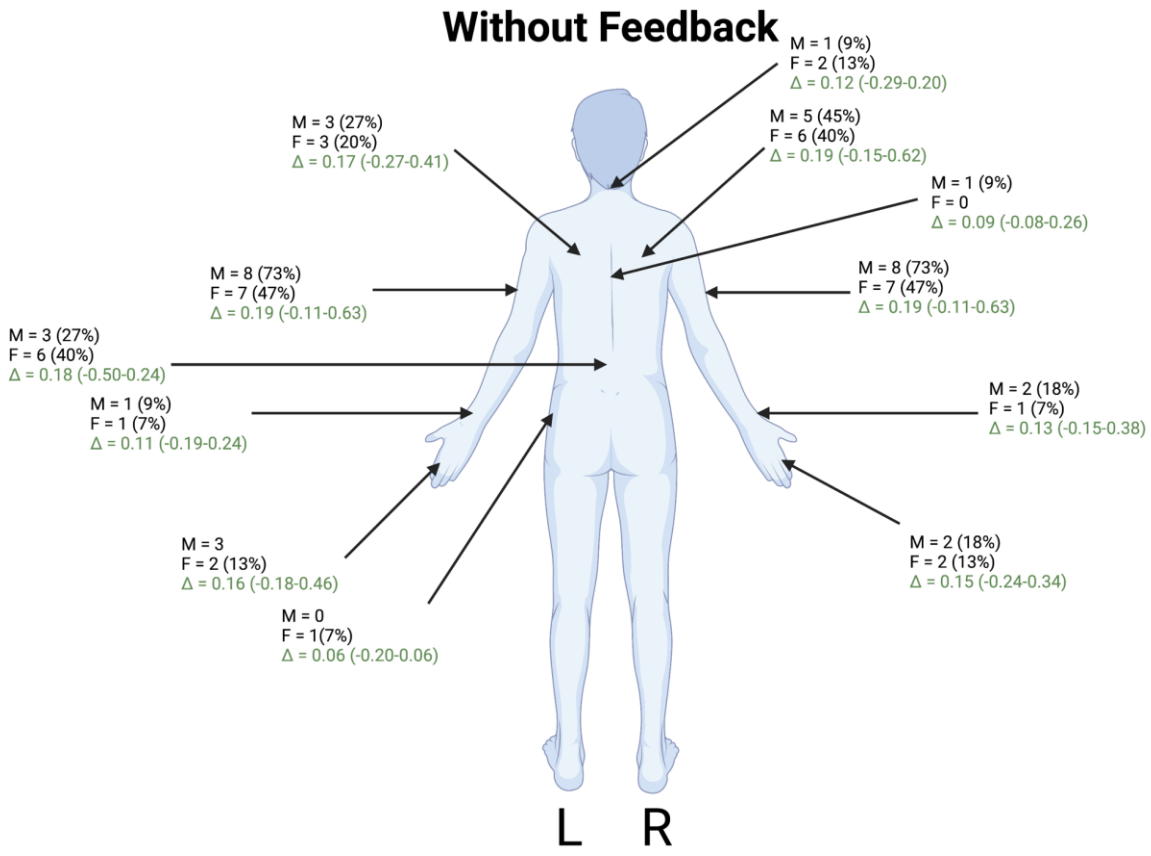


Figure 23. Brief Pain Inventory- Back Without Feedback

4.1.10 Case Studies of those unable to perform CPR

Of the 26 participants, three females were unable to perform the full 10-minutes of CPR for either session. Participants stopped between 4:26 and 7:28 minutes. All three participants were unable to complete the full 10-minutes of CPR for each of their visits. Participants only expressed that they wished to stop, none of them had a specific reason for terminating the CPR before the 10-minutes were up. Anecdotally, one of the participants was very apathetic about her participation in the study. It is likely that she stopped early merely because she just did not want to perform CPR anymore. These three participants were included in demographic descriptions and physiologic analyses but were excluded from CPR quality and regression analyses. Mean

differences between females who did not finish (DNF) the 10-minute CPR bout and the female cohort are reported in tabular form below (Table 17). There was not a significant difference in demographics or fitness assessments. There was also not a significant difference in post-CPR Global RPE, or regional RPEs (triceps, abdominals, low back, knees) between those who could and could not complete the full bout of CPR. However, it must be noted that these comparisons have been made with very uneven sample sizes, and results may not be an accurate depiction of the relationship between perceived exertion and ability to perform 10 minutes of CPR.

Table 18. Demographic Comparison of Females Unable to Complete 10-Minutes of CPR to Female Cohort

	All Females	**DNF**	**Mean Difference**
Age (IQR)	25 (22-34)	25 (23-35)	4 (-18-27)
Height (cm) (SD)	167 (± 6)	169 (± 10)	-3 (-12-6)
Weight (kg) (SD)	61.6 (± 10.2)	70.6 (± 9.7)	-11 (-24.4-1.8)
BMI (kg/m^2) (SD)	22.2 (± 3.2)	24.9 (± 4.8)	-3.4 (-7.6-0.8)
Body Fat (%) (SD)	21.4 (± 6.4)	22.1 (± 2.6)	-0.9 (-10-8.4)
$\dot{V}O_2$ Max (ml/kg/min) (SD)	35.7 (± 7.7)	34.9 (± 5)	1.1 (-10-12.2)
Grip Strength (kg)	29.8 (± 5.4)	33.2 (±7.4)	-4.3 (-11.7-3)
Standard Push-up Position (SD)	12 (± 11)	12 (± 13)	0 (-15-15)
Modified Push-up Position (IQR)	24 (26-16)	26 (35-18)	-5 (-25-16)

There were an additional two participants, one male (age 20) and one female (age 74), who performed compressions for the full duration, but compressions were so shallow that they were not reliably detected by the Laerdal CPR Meter. Because of this, they were excluded from CPR quality metrics analyses (compression rate, depth, force, release force), but included in the physiologic assessments. Despite being unable to perform adequate compressions, they had similar

physiologic responses to those whose compressions were detectable by the CPR Meter, suggesting that their efforts were not radically different.

4.1.11 Regression Analyses

Because CPR quality metrics were assessed over time, the dataset was formatted as panel data to be clustered by individual participants. Univariate analyses were performed for each of the four CPR quality metrics (compression rate, compression depth, compression force, release force) and the following factors: time, age, gender, height, weight, BMI, body fat percentage, $\dot{V}O_2$ Max, muscular strength, and muscular endurance (both modified push-ups and standard push-ups). Any univariate analysis with a $p \leq 0.15$ was added to the final multivariate regression model (Bursac et al., 2008; Heinze et al., 2018). Refer to Figure 9 for graphical representation of CPR quality metrics over time.

4.1.11.1 Regression- Compression Rate

Time, $\dot{V}O_2$ Max, average grip strength, and number of modified push-ups had a univariate association with compression rate and were included in the final multivariate regression model. Ultimately, only time was a significant predictor of compression rate ($p<0.001$; 95% CI 0.02-0.04). The model overall accounted for 17% of variability in compression rate, and accounted for 9.5% of variability within participants, and 20.5% of variability between participants ($p<0.001$).

4.1.11.2 Regression- Compression Depth

Gender, feedback, number of modified push-ups and number of standard push-ups had a univariate association with compression depth and were included in the final multivariate

regression model. Both feedback ($p<0.023$; 95% CI 0.62-8.3) and number of modified push-ups ($p=0.032$; 95% CI 0.03-0.75) were predictors of compression depth. The model overall accounted for 24% of variability of compression depth, 37% of variability between participants, and 10% of variability within participants ($p<0.001$).

4.1.11.3 Regression- Compression Force

Gender, number of standard and modified push-ups, and feedback had a univariate association with compression force and were included in the multivariate model. Both feedback ($p<0.023$; 95% CI -8.3 to -0.62) and number of modified push-ups ($p=0.032$; 95% CI -0.75 to -0.03) were predictors of compression depth. The model overall accounted for 24% of variability of compression depth, 37% of variability between participants, and 10% of variability within participants ($p<0.001$).

4.1.11.4 Regression- Release Force

Gender, height, weight, BMI, body fat percentage, average grip strength and both standard and modified push-ups had a univariate association with release force and were included in the multivariate model. Gender ($p=0.032$; 95% CI 0.4-9.6), body fat percentage ($p=0.10$; 95% CI -0.42 to -0.06), and average grip strength ($p=0.013$; 95% CI 0.03-0.26) were significant predictors of release force. Overall, the model accounted for 49% of release force variability, and 68% of variability between participants. The model was not predictive of release force variation within participants.

5.0 Discussion

A total of 26 participants were enrolled in this study. Male participants were taller, heavier, had a higher BMI, and lower body fat percentage compared to female participants. Males were also stronger and had more muscular endurance, but there was not a significant difference in aerobic capacities (Tables 5-8).

CPR quality declined with time. Higher muscular strength and endurance, lower body fat percentage, and the presence of feedback, are primary factors contributing to higher CPR quality (Table 18).

Males generally performed compressions at a faster rate, with more depth, force, and release force. There was an interaction effect between gender and CPR feedback on CPR depth and force, with females performing compressions with better depth and force in the presence of feedback (Table 10, Figure 9). However, in multivariable regression analyses, gender was not independently associated with CPR depth or force when adjusted for feedback and strength. Post-CPR lactate levels immediately after, and five minutes post-CPR increased significantly from baseline. However, this increase did not differ between males and females, suggesting that there was not a significant difference in muscular exertion. Post-CPR lactate was higher in the presence of feedback, suggesting participants worked harder with feedback, however this difference was not statistically significant. Global and regional RPE increased over time in both males and females, regardless of feedback presence, and regional RPE did not differ. Global RPE only differed in the presence of feedback, with females reporting higher RPEs (Table 16, Figure 15). Global RPE also increased with heart rate, and post-CPR RPE increased proportionately to the increase in lactate from baseline in both men and women. Otherwise, global, and regional RPE did not differ based on feedback presence or gender. Peak $\dot{V}O_2$, heart rate, and $\dot{V}O_2$ over time also did

not significantly differ based on feedback or gender. Respirations increased over time between men and women, however this increase did not differ between them. Respiration rate and heart rate increased over time, and lactate increased significantly over time. All three of these indicate that individuals put forth a substantial amount of both muscular and aerobic exertion. The culmination of an increase in lactate, heart rate, and respiratory rate during CPR are likely contributing factors to the increase in Global RPE. However, we did not collect RPE specifically for breath work, so this connection is only speculation.

Gender was independently associated with release force in adjusted models. Males have a significantly higher release force. However, a higher release force is indicative of providers leaning on the manikin which prevents the chest from fully recoiling. This suggests that females perform better CPR with regards to release force. This finding is similar to a recent study that also found females performing CPR had better chest recoil during compressions than males (Lancaster et al., 2022).

Table 19. Variables Associated With CPR Quality Metrics

CPR Quality Metric	**Associated with**
Compression Rate	Time
Compression Depth	Feedback, Muscular Endurance (Modified Push-ups)
Compression Force	Feedback, Muscular Endurance (Modified Push-ups)
Release Force	Gender, Body Fat Percentage, Muscular Strength (Grip Strength)

Results from this study agree with some studies and are contradictory to others. Like Baubin et al.'s study, participants in this study commonly reported fatigue and pain in their arms, knees and back (Baubin et al., 1996). This study agrees with results from a study by Ochoa et. al., and another by Ock et. al., that determined CPR quality did not differ based on age, $\dot{V}O_2$ max,

height, weight, or gender (Ochoa et al., 1998). However, unlike some of Baubin's other results, this study did not find that a higher aerobic capacity was associated with higher quality CPR or an ability to perform CPR for longer durations. The three women in this study who could not complete the full 10-minute bout did not significantly differ from other female participants.

While these study results agree with Ock et al. on many variables, they do not agree when it comes to the association of muscular strength and CPR quality. Ock and colleagues, and another study by Abelairas-Gómez et al., both found that only muscular strength was associated with compression quality (Abelairas-Gómez et al., 2018; Ock et al., 2011). The same study performed by Lancaster and colleagues that similarly found that females lean less while performing CPR, found that anaerobic power, and muscular strength were related to compression depth (Lancaster et al., 2022). Contrarily, this study found that muscular endurance was associated with compression depth and force, while muscular strength was associated with release force.

Other studies disagree altogether. Some studies have found differences in CPR quality based on gender, height, weight, BMI, and aerobic capacities; some have found that anthropometrics (height, weight, BMI) matter more for females than males (Ashton et al., 2002; Hasegawa et al., 2014; Russo et al., 2011; Shin et al., 2014). There are some plausible reasons for these varying results. The primary being that some of these studies are older and were conducted using now outdated CPR breath-to-compression ratios, or asked participants to perform CPR for longer or shorter periods. Some of these studies were also full rescue simulations such as performing CPR after a water rescue, which will also cause differing results. Different variations of CPR can cause providers to fatigue at faster or slower rates. Studies also used a variety of methods to assess muscular strength, endurance, and aerobic capacities (such as maximal bench press, and sub-maximal exercise tests). There are also very few studies that directly measured $\dot{V}O_2$ over time during CPR. Thus, it is difficult to compare and contrast results across studies when the

methodologies, and areas of focus are vastly different. However, this does not mean that these studies were done in vain. As CPR guidelines evolve, this work should continue to be repeated to determine if provider characteristics contribute more or less to CPR quality based on how the guidelines change.

5.1 Limitations

This study has several limitations. The number of male and female participants is unbalanced, with fewer men participating than females. While assessing $\dot{V}O_2$ during CPR was a primary outcome, wearing a facemask during CPR could have posed a big enough nuisance to distract participants and interfere with CPR quality. As with any CPR simulation study, the fact that there is not an 'emotional' aspect to performing the compressions could also contribute to decreased CPR quality than if the participant was performing CPR in a real-life situation. CPR was performed with minimal background noise. Performing CPR for 10-minutes in relative silence could also be monotonous to participants and cause them to lose focus on the task at hand. Participants performed CPR while kneeling on a foam pad to protect their knees from the tile floor. Real-life scenarios are likely to occur on a multitude of surfaces such as concrete or hardwood floors which may also impact pain and quality of CPR. While anthropometrics and angles relative to the manikin were observed, biomechanics was not considered in this study. All participants were also relatively young and healthy and may not be a completely accurate depiction of the general population.

5.2 Future Directions

The presented data suggest multiple opportunities to improve CPR quality. The common thread between each of these directions is individualizing CPR training and performance. Altering how rescuers are trained to perform CPR, how often they should rest, or how often they should alternate based on individual characteristics may drive CPR quality improvement.

Average EMS response times are 5-18 minutes within Allegheny County, and upwards of 30 minutes in Southwestern PA (P. V. Osdol, 2015). Providing high-quality CPR for that long can be a daunting task for even the fittest of individuals. Providing an aspect of scripted 'coaching' or motivation could potentially improve CPR quality. Telling rescuers, they are "doing a great job," or that "EMS will be arriving shortly, you only need to hang in there for a few short minutes" may improve their perceived fatigue and allow them to perform higher quality compression. In the situation of a lone rescuer, it may also prove beneficial for 9-1-1 operators to provide guided 'pauses' when individuals need to perform CPR for prolonged periods. Minimizing no-flow time is crucial however, if the compressions are not perfusing adequate blood back to the brain, a brief pause allowing the provider to rest may be a reasonable tradeoff if compressions improve significantly after said pause. Even though the pause may be brief, it may be long enough for the individual to *perceive* that they have had time to recover. One method of determining when to administer a pause could be based on an individual's perceived exertion. This could also be applied in the situation that multiple providers are present. The AHA recommends alternating providers every 2 minutes. However, this timeframe was chosen arbitrarily. It may be more prudent to alternate more frequently if a provider begins to fatigue more quickly. This line of research could be expanded to determine if there is a specific range on the RPE scale that indicates a pause is warranted and its optimal duration, or if a provider should alternate sooner than every 2 minutes.

As noted in the limitations, biomechanics were not taken into consideration for this study. However, results do note that body angles relative to the manikin did not differ between men and women, despite their varied statures and body habitus. It should be investigated if people of different statures should kneel closer or farther away from the manikin / victim (e.g. should people taller than 6-foot kneel closer or farther away) so that an individual can improve their compression efficiency. Suggesting providers alternate sides of the victim on which they perform CPR or alternating how they interlace their hands may also adjust their biomechanics enough to allow providers a reprieve from their fatigue.

The data also do not suggest that men or women are better at performing CPR over the other. Rather, it suggests that men and women need to focus on different areas of CPR performance. Men should focus on not leaning on the manikin between compressions, while women should focus on performing compressions with more depth and force.

Updated technology may also work in the favor of improving an individual's ability to perform CPR. Companies such as Laerdal are continually releasing phone applications such as 'QCPR Learner' and 'QCPR Trainer' to teach CPR to the lay population. In the future, these apps could help provide individual-specific feedback on how to administer proper compressions based on a user's reported characteristics (reported height, weight, etc.).

Provider fitness unquestionably plays a role in CPR quality. While it is implausible to implement a fitness program for the general population to improve CPR, fitness programs for EMTs, paramedics, and other medical professionals could be warranted. As of 2014, only 30% of fire departments in the United States require their employees to pass an annual fitness test, and standards to pass these tests vary from department to department (Storer et al., 2014). It was unable to be determined what percentage of EMS agencies require similar fitness standards. Establishing a fitness test and program designed specifically to the needs of EMS providers could not only

improve their CPR quality, but also improve the overall quality of patient care (e.g., carrying patients down flights of stairs, performing lift assists etc.) and prevent on-the-job injuries.

Fitness programs for first responders would need to be comprehensive of both strength and resistance, and cardiovascular training to improve cardiovascular health, muscular strength, and endurance. Strength and resistance training should focus on the posterior chain and compound movements including deadlift and squat variations. It should also target muscles recruited during CPR such as biceps, triceps, and abdominal muscles to prevent them from rapidly fatiguing during CPR. Strength training will make it easier and safer for first responders to lift heavy patients and carry heavy equipment which will reduce their risk of injury, while also likely making it easier for individuals to perform high-quality CPR. Endurance can also be improved with the implementation of cardiovascular training, specifically high intensity interval training (HIIT) to improve cardiovascular fitness and anaerobic capacity.

Table 20. First Responder Fitness Program Exercises

Area of Focus	**Example Exercises**
Posterior Chain / Compound movement	Romanian Deadlift One-legged Deadlift Sumo Squat Overhead Squat Split Squat Standard Squat Hip Thrusts Barbell Good Morning Bent Over Row Olympic Lifts (Dumbbell Snatch, Turkish Get-ups, Barbell Clean & Press)
CPR-Specific	Standard Bicep Curls Wide Bicep Curls Hammer Bicep Curls Triceps Dips Triceps Kickbacks Triceps Skull-Crusher Triceps Extension High Plank

	Low Plank
Cardiovascular- Anaerobic	HIIT Plyometrics Kettlebell Swings Burpees Box Jumps Lateral bounds Mountain Climbers Jumping Jacks
Cardiovascular- Aerobic	Long slow distance (LSD) Running Rowing Hiking Swimming Biking

5.3 Conclusions

Performing CPR is unquestionably a physically demanding feat. In a real-life scenario it can also be both mentally and emotionally draining. During CPR, providers are often unaware of their fatigue, and consequently, they are also unaware that their CPR quality is degrading as they become increasingly more fatigued. We found that the most influential factors contributing to the decline of CPR quality are time, the presence of real-time CPR quality feedback, and provider characteristics of gender, muscular endurance, muscular strength, and body fat percentage. However, the data do not suggest that males or females are better at performing CPR than the other, just that they are better at performing different aspects of CPR (men generally perform compressions with more depth and force, while women lean less on the manikin between compressions). Our data confirm the rapid decline in CPR quality over time that is one of the reasons the AHA recommends switching providers every two minutes when multiple providers are present. We additionally report that men have more leaning than women. Also, individuals

with less upper body strength, which includes more women than men, usually perform chest compressions with less force or depth but can correct that performance when provided with real-time feedback. These observations suggest opportunities for targeted training or feedback to improve performance of CPR.

APPENDIX A

Appendix A.1 Phone screening

Work of CPR Phone Script

Staff: Hi, (insert potential subject's name here), this is (insert your name here) from the Applied Physiology lab. You have indicated to us that you would be interested in new studies performed in the APL. We have a new study that is looking to look at the work of cardiopulmonary resuscitation (CPR). Does this sound like something that you'd be interested in?

If no: Thank you for your time. (End call)

If yes: Great! Before we can enroll you in the study we need to ask you a few more questions to make sure that you're eligible to participate in the study. It should take less than 3 minutes of your time.

If any of these questions make you uncomfortable, you do not have to answer.

I will keep all information that I receive from you by phone, including your name and any other identifying information confidential.

The purpose of these questions is to determine whether you may be eligible to participate in the study. Additional screening at a later time may be necessary beyond answering these questions. Please remember that your participation is voluntary; you do not have to answer these questions. Please feel free to stop me at any time if you have any questions or concerns.

Do I have permission to ask you these questions?

If no: Thank you for your time. (End call)

If yes: Thank you.

_____	_____
Signature of Person Obtaining Consent	Role in Research Study
_____	_____
Date	Time

1. What is your current age?
2. Do you have a history of cardiovascular disease, such as a prior heart attack, coronary revascularization, congenital heart disease stroke, liver disease or impairment?
3. Do you take any medications that may blunt (lessen) your physiologic response to exercise or stress? For example a beta blocker
4. Are you currently pregnant?
5. Do you know your approximate height and weight?
6. Do you feel as though you have any underlying musculoskeletal problems that may prevent you from performing CPR?

If eligible:

Based on your answers to these questions, it appears you may be eligible to participate in this study.

Would you like to schedule a time to meet with the research team to obtain more details about the research study?

Obtain subject's contact info

If not eligible:

Unfortunately, based on your responses, you are not eligible for the study.

For either group:

Thank you for taking the time to talk with me today. If you have any questions, please feel free to contact me. My name is (your name here) and I can be reached at 412-864-1119.

Appendix B

Appendix B.1 PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q+)

2020 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** _____	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://apps.who.int/iris/handle/10665/44399).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

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2020 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm

If the above condition(s) is/are present, answer questions 3a-3d If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you currently have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes

If the above condition(s) is/are present, answer questions 5a-5e If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

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6. **Do you have any Mental Health Problems or Learning Difficulties?** This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome

If the above condition(s) is/are present, answer questions 6a-6b If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

7. **Do you have a Respiratory Disease?** This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure

If the above condition(s) is/are present, answer questions 7a-7d If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. **Do you have a Spinal Cord Injury?** This includes Tetraplegia and Paraplegia

If the above condition(s) is/are present, answer questions 8a-8c If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. **Have you had a Stroke?** This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event

If the above condition(s) is/are present, answer questions 9a-9c If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. **Do you have any other medical condition not listed above or do you have two or more medical conditions?**

If you have other medical conditions, answer questions 10a-10c If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: _____

_____

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

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If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
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The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

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11-01-2019

Appendix C

Appendix C.1 DATA SHEET

Relative, Perceived and Actual Work of CPR in the Lay Population
STUDY: 19050375

Subject # _____
Date _____

☐ **Visit: #1 Screening**

☐ Ensure subject has provided written consent

☐ Ensure subject is 18 years of age or older

☐ Ensure subject is CPR certified as verified by Red Cross or AHA (may NOT be ALS certified)

☐ Obtain demographic information

☐ Height (cm) _____

☐ Weight (Kg.) _____

☐ Age (yrs.) _____

☐ Sex _____

☐ Race _____

☐ Ethnicity _____

☐ PAR-Q+ questionnaire explained _____ PAR-Q+ questionnaire administered _____

☐ Provide brief medical exam

Pregnancy Test: Not applicable / Positive / Negative

☐ Place ECG monitor Resting HR _____

☐ Place BP cuff Resting BP _____ / _____

☐ Oral Temp: _____ °C

☐ Auscultation of lungs and heart tones

Notes_____

_____

Subject # _____
Date _____

☐ ECG Interpretations:

_____

_____

☐ No reported history of the following:

- ☐ History of Cardiovascular Disease (MI, coronary revascularization, congenital heart disease etc.)
- ☐ Vascular Disease (ex. history of stroke)
- ☐ Any form of tobacco use (smoking, chewing, vaping, etc.)
- ☐ AV Block, interventricular conduction delays, or bradycardia on resting 12-lead
- ☐ Positive urine pregnancy test
- ☐ BMI > 30
- ☐ Currently taking heart rate-limiting medications (ex. Beta blockers)
- ☐ Taking medication that would make protocol unsafe for the subject
- ☐ Hypertension (SBP >139 or DBP > 89)
- ☐ Current musculoskeletal injuries that would prohibit safe performance of a maximal exercise treadmill test, or CPR

Date / Time / Signature: _____

Subject # _____
Date _____

o Visit #2: Part A- Exercise Capacity

☐ Ensure subject has not had any recent changes in health since initial visit

☐ Ensure subject has fasted for 3 hours

☐ Ensure subject has not had caffeine for 6 hours

Pregnancy Test: Not applicable / Positive / Negative

☐ Body Fat Assessment:
Males:
Chest: _____ Chest: _____ Chest: _____ AVG: _____

Abdomen: _____ Abdomen: _____ Abdomen: _____ AVG: _____

Thigh: _____ Thigh: _____ Thigh: _____ AVG: _____

Females:
Triceps: _____ Triceps: _____ Triceps: _____ AVG: _____

Suprailiac: _____ Suprailiac: _____ Suprailiac: _____ AVG: _____

Thigh: _____ Thigh: _____ Thigh: _____ AVG: _____

☐ Anthropometrics (taken to the nearest 0.1 cm):

Upper leg length: _____ (cm)
Have subject sit in chair with legs bent at a 90° angle while sitting up straight and relaxed. Measurement taken from the top-center of the patella to the inguinal crease

Waist circumference: _____ (cm)
Measured with subject standing in upright, measured from above the uppermost lateral border of the right ilium

Hip circumference: _____ (cm)
Measured with subject standing upright, arms hanging loosely at their sides, legs slightly apart, taken from maximal circumference of the hips

Chest expansion inhalation: _____ (cm)
Subject will stand upright, feet slightly parted. Measurement taken from the xyphoid notch. Prior to first measurement subject will be asked to take in a big breath and blow all the air out. They will then take a large breath in and hold it until measurement is made. Immediately after, ask subject to exhale to their fullest extent and hold until measurement is made

Subject # _____
Date _____

Chest expansion exhalation: _____ (cm)

Hip to shoulder distance: _____ (cm)
Measured with subject standing upright, distance between the iliac crest and the acromion process

Shoulder to shoulder distance: _____ (cm)
Measured with subject standing up, arms resting at their sides, measurement taken from the back of the subject. Distance defined as distance between acromion process of left and right shoulder

Arm length: _____ (cm)
Measured with subject standing upright, arms resting comfortably at side. Distance defined as distance from acromion process to tip of the middle finger

Upper arm length: _____ (cm)
Measured with subject standing in upright position, right arm bent at 90° below elbow, with right palm facing up. Measurement taken from uppermost edge of posterior border of the scapula extending from acromion process to the top of the olecranon process

Arm span: _____ (cm)
Measured with subject standing upright arms outstretched in a 'T' position with their arms parallel to the ground, at shoulder height. Defined as the distance from the top of the middle finger on left arm, across nipple line of the chest to the tip of the right middle finger

☐ Explain BORG 6-20 Rating of Perceived Exertion Scale to subject and ensure their understanding of it

☐ Have subject step onto treadmill and secure HR monitor

☐ Apply metabolic cart face mask to subject

☐ Baseline Lactate level (PreTreadmill Protocol) _____

☐ Begin Modified Bruce Treadmill Protocol

- ☐ Measure HR every min
- ☐ Measure Respiratory Rate per minute
- ☐ Measure Blood Pressure every 3 minutes
- ☐ RPE within the last 15 seconds of each 3 minute stage

☐ Protocol start time_____

Subject # _____
Date _____

Minute	RPE	HR	Resp. Rate	SBP	DBP	RER
0 (Baseline)						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

Subject # _____
Date _____

21						
22						
Immediately Post Exercise						

☐ Lactate level (Post-Treadmill Protocol) _____

☐ Protocol end time _____

☐ Monitor vital signs every 5 minutes after completion of treadmill protocol until HR < 100 or returns to resting rate

Recovery Monitoring

Minute	HR	SBP	DBP	Lactate
0				
5				
10				
15				
20				
25				
30				
35				
40				
45				

Abnormal Vital Signs (for recovery purposes only)

SBP<90 or > 140 mmHg RR <10 >24
HR <50 > 110 bpm T <96.5°, >99.5° F (<35.8°, >37.5° C)

Subject # _____
Date _____

o Visit #2: Part B- Muscular Strength

☐ Ensure at least 20 minutes of recovery prior to initiating strength test

☐ Ensure subject understands how to use the hand-grip dynamometer

☐ Have subject hold the dynamometer in their dominant hand, with their arm at a right angle, and their elbow at the side of their body

☐ Have the subject squeeze the dynamometer to their maximum effort for 5 seconds. Record the average of three measurements

☐ Time of assessment_____

Measurement #1_____

Measurement #2_____

Measurement #3_____

Average Measurement (Maximal Grip Strength) _____

☐ **Visit #2: Part C- Muscular Endurance**

☐ Ensure at least 20 minutes of recovery prior to initiating push-up test

☐ Ensure subjects understand how to perform the push-up endurance test

☐ Which push-up position has the subject been randomized to perform first?

Standard / Modified (knee position)

☐ Time of assessment 1_____

☐ Time of assessment 2_____

☐ Number of standard push-ups _____

☐ Number of modified push-ups _____

☐ Test is terminated when subject is unable to maintain adequate technique for two repetitions

Subject # _____
Date _____

Subject may go home when they meet the following criteria:

- ☐ HR has returned to baseline or < 100 BPM
- ☐ BP < 140 / 90
- ☐ At the discretion of overseeing physician / APP

Date / Time / Signature_____

Subject # _____
Date _____

o Visit #3: CPR Performance 1

☐ Randomized to perform which CPR variation for visit 1

CPR with feedback / CPR without feedback

☐ Ensure no health changes since screening

☐ Pregnancy Test: **Not applicable / Positive / Negative**

☐ Ensure subject dons a heart monitor and metabolic cart face mask

☐ Ensure subject is positioned correctly next to a CPR manikin

☐ Ensure subject understands the BORG RPE Scale (visual references will be provided)

☐ Use a goniometer to measure the subject's arm and spine angle relative to the CPR manikin

☐ Arm angle_____ ☐ Spine angle_____ ☐ Wrist angle_____

☐ Baseline Regional RPE

	RPE
Lower back	
Triceps	
Abdominal muscles	
Knees	

CONTINUED ON NEXT PAGE...

o Begin CPR session

Subject # _____
Date _____

Minute	Lactate	HR	Systolic BP	Diastolic BP	Global RPE
0 (Baseline)					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Immediately Post CPR					
5 Min-Post CPR					

☐ Immediately post CPR Regional RPE

ASK SUBJECTS WHICH REGION IN WHICH THEY FEEL THE MOST FATIGUED, THEN IN THE ORDER OF TABLE BELOW

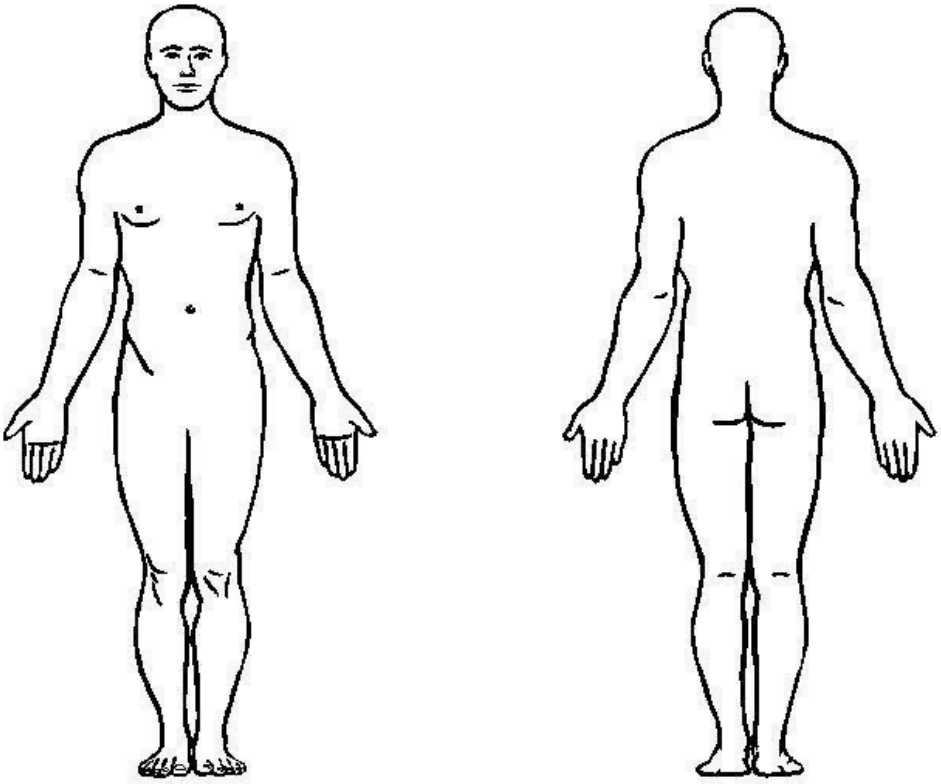
	RPE
Lower back	
Triceps	
Abdominal muscles	
Knees	

CONTINUED ON NEXT PAGE…

Subject # _____
Date _____

☐ Administer Brief Pain Inventory Scale

On the diagram, shade in the areas where you feel pain. Put an "X" on the area that hurts the most.



On a scale of 0-10, 0 indicating "no pain," and 10 indicating "pain as bad as you can imagine," please rate your pain by marking the box beside the number that tells how much pain you have right now.

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐10

"no pain" "pain as bad as you can imagine"

CONTINUED ON NEXT PAGE…

Subject # _____
Date _____

☐ Email MRX monitor data to holquistkl@upmc.edu

☐ File name_____

☐ Subject HR < 100 BPM & study physician / APP has deemed it appropriate for subject to go home

Date / Time / Signature_____

o Visit #4: CPR Performance 2

Subject # _____
Date _____

☐ Randomized to perform which CPR variation for visit 2

CPR with feedback / CPR without feedback

☐ Ensure no health changes since screening

☐ Pregnancy Test: **Not applicable / Positive / Negative**

☐ Ensure subject dons a heart monitor and metabolic cart face mask

☐ Ensure subject is positioned correctly next to a CPR manikin

☐ Ensure subject understands the BORG RPE Scale (visual references will be provided)

☐ Use a goniometer to measure the subject's arm and spine angle relative to the CPR manikin

☐ Arm angle_____ ☐ Spine angle_____ ☐ Wrist angle_____

☐ Baseline Regional RPE

	RPE
Lower back	
Triceps	
Abdominal muscles	
Knees	

CONTINUED ON NEXT PAGE...

o Begin CPR session

Minute	Lactate	HR	Systolic BP	Diastolic BP	Global RPE
0 (Baseline)					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Immediately Post CPR					
5 Min-Post CPR					

☐ Immediately post CPR Regional RPE

ASK SUBJECTS WHICH REGION IN WHICH THEY FEEL THE MOST FATIGUED, THEN IN THE ORDER OF TABLE BELOW

	RPE
Lower back	
Triceps	
Abdominal muscles	

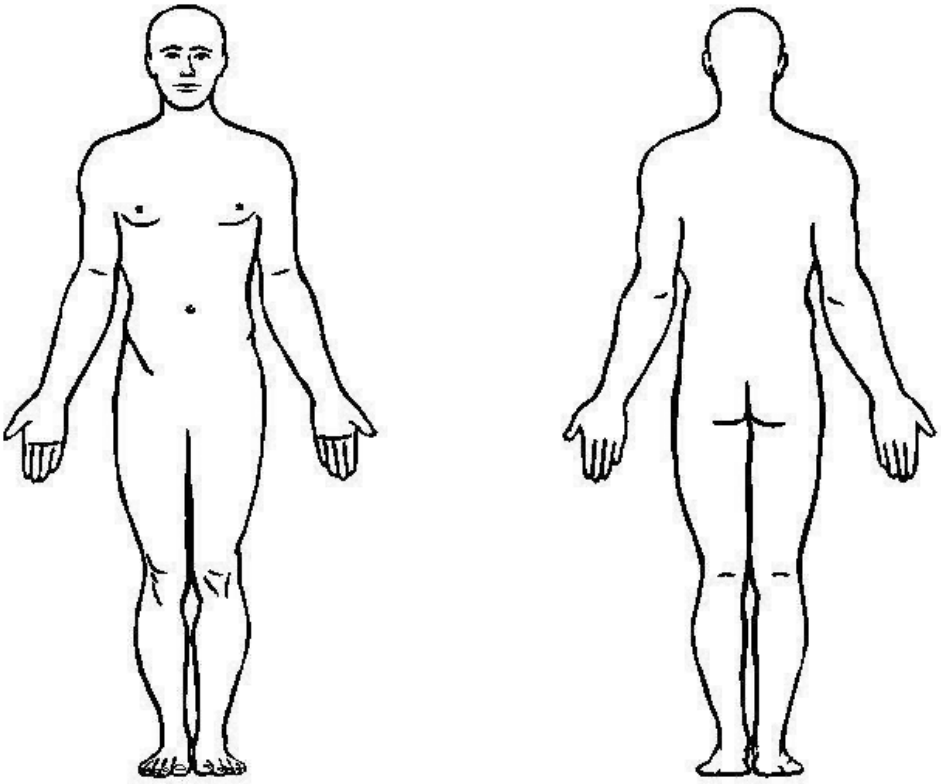
Subject # _____
Date _____

Knees	

CONTINUED ON NEXT PAGE…

☐ Administer Brief Pain Inventory Scale

On the diagram, shade in the areas where you feel pain. Put an "X" on the area that hurts the most.



On a scale of 0-10, 0 indicating "no pain," and 10 indicating "pain as bad as you can imagine," please rate your pain by marking the box beside the number that tells how much pain you have right now.

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐10

"no pain" "pain as bad as you can imagine"

Subject # _____
Date _____

CONTINUED ON NEXT PAGE…

☐ Email MRX monitor data to holquistkl@upmc.edu

☐ File name_____

☐ Subject HR < 100 BPM & study physician / APP has deemed it appropriate for subject to go home

Date / Time / Signature_____

Appendix D

Appendix D.1 BORG 6 – 20 for Treadmill and CPR:

You are about to undergo a treadmill exercise test. This scale contains numbers from 6 – 20 that we will ask you to use to rate your perception of physical exertion. The perception of physical exertion is defined as "the intensity of the subjective effort, strain, discomfort, and/or fatigue that you feel during an exercise task." We use this scale so that you may translate into numbers your feelings of exertion while exercising. These feelings should be general about the body as a whole.

The range of numbers on the scale represent a range of feelings from "no exertion at all" to "maximal exertion." In order to help you select a number that corresponds to your subjective feelings, please consider the following: When the exertion feels "Extremely light," respond with a number 7. For example, you should respond with a 7 when you are walking slowly on level ground. When the exertion feels "Extremely hard," respond with a number 19. For example, a rating of 19 would be appropriate when your feelings of exhaustion are the same as your memory of how you felt during the most physically exhaustive work you have ever done. Do not over or under estimate your feelings of exertion. We ask that you simply rate your feelings induced by the exercise at the moment. There are no right or wrong answers, start with any number that feels appropriate to you at that moment.

Appendix D.1.1 Borg 6-20 For CPR Compressions:

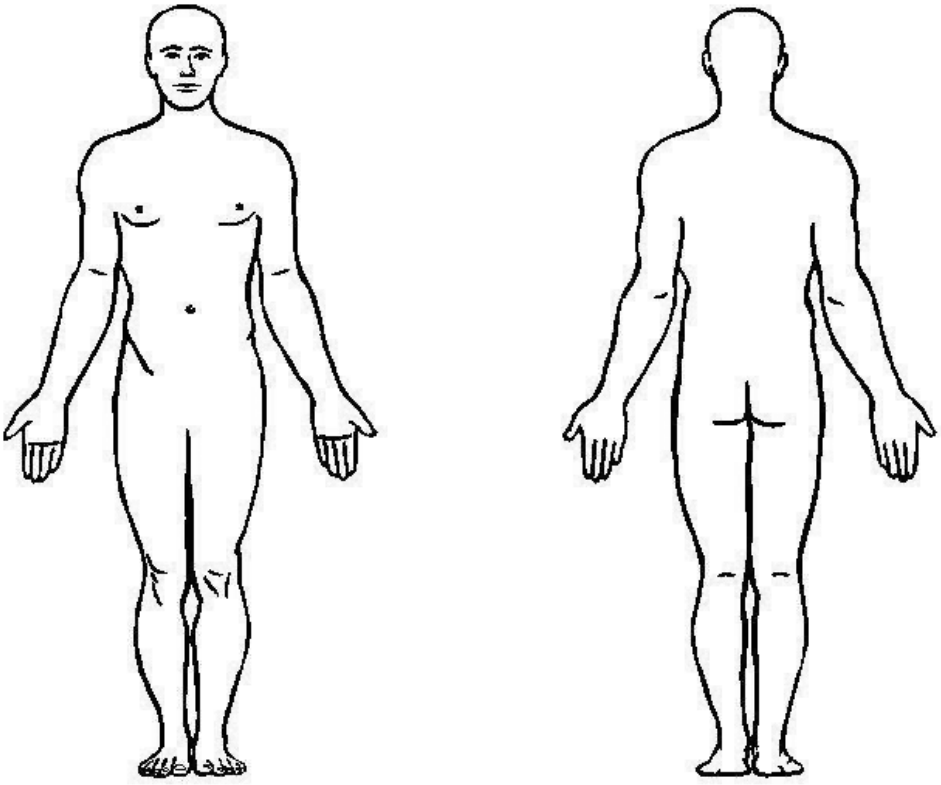
You are about to perform a 10-minute bout of CPR. This scale contains numbers from 6 – 20 that we will ask you to use to rate your perception of physical exertion. The perception of physical exertion is defined as "the intensity of the subjective effort, strain, discomfort, and/or fatigue that you feel during an exercise task." We use this scale so that you may translate into numbers your feelings of exertion while exercising. These feelings should be general about the body as a whole with the exception of at two timepoints. At baseline, and immediately after the compression bout we will ask you to use this scale to rate your region-specific feelings of exertion in your triceps, lower back, abdominal muscles, and your knees. To prevent any confusion when we ask you to rate your exertion, we will either ask you to rate your overall feelings of exertion, or to rate your feelings of exertion in your triceps, lower back, abdominal muscles, or knees.

The range of numbers on the scale represent a range of feelings from "no exertion at all" to "maximal exertion." In order to help you select a number that corresponds to your subjective feelings, please consider the following: When the exertion feels "Extremely light," respond with a number 7. For example, you should respond with a 7 when you are walking slowly on level ground. When the exertion feels "Extremely hard," respond with a number 19. For example, a rating of 19 would be appropriate when your feelings of exhaustion are the same as your memory of how you felt during the most physically exhaustive work you have ever done. Do not over or under estimate your feelings of exertion. We ask that you simply rate your feelings induced by the exercise at the moment. There are no right or wrong answers, start with any number that feels appropriate to you at that moment.

Appendix E

Appendix E.1 BRIEF PAIN INVENTORY

On the diagram, shade in the areas where you feel pain. Put an "X" on the area that hurts the most.



On a scale of 0-10, 0 indicating "no pain," and 10 indicating "pain as bad as you can imagine," please rate your pain by marking the box beside the number that tells how much pain you have right now.

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐10

"no pain" "pain as bad as you can imagine"

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