

COMPARING SUBJECTIVE FATIGUE DURING TWO CARDIOPULMONARY
RESUSCITATION (CPR) MODELS

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Rachel AnneMarie Reichel

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Advanced Athletic Training

April 2019

Fargo, North Dakota

North Dakota State University
Graduate School

Title

COMPARING SUBJECTIVE FATIGUE DURING TWO
CARDIOPULMONARY RESUSCITATION (CPR) MODELS

By

Rachel AnneMarie Reichel

The Supervisory Committee certifies that this *disquisition* complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Katie Lyman

Chair

Kyle Hackney

Ronda Peterson

Approved:

4/12/19

Date

Yeong Rhee

Department Chair

ABSTRACT

Bystanders are the first rescuers to perform CPR for patients suffering from cardiac arrest. Compression-only CPR decreases the amount of interruption time between compressions but increases the fatigue of the rescuer. In this study, participants were certified as lay rescuers and performed two compression-only CPR protocols for eight minutes and 59 seconds. The two protocols were 30 compressions to a 10-second break and continuous compressions with as many 10-second breaks as needed. Body mass index and hand grip strength were collected before the CPR protocols. Rate of Perceived Exertion scores were taken at three, six and nine minutes during each protocol. There were increased fatigue levels during the continuous compressions protocol at all three time intervals. A relationship between hand grip strength and the proper depth was determined for the 30:10 protocol as well as a relationship between hand grip strength and the continuous compressions fatigue levels.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank God for everything he has done for me. I would like to thank my family, especially my sister, for their support and love throughout graduate school. I would not be the woman or even athletic trainer I am today if it wasn't for her. I also would like to thank my friends for being there for me these last couple years. I could not have gotten through all this without my family and friends.

Dr. Katie Lyman has been a pivotal role in my graduate career. She has pushed me out of my comfort zone and has helped me grow as not only a student and athletic trainer but also as a person. Even though there were bumps in the road, I cannot thank her enough for not giving up on me and continuing to encourage me.

I would like to thank Dr. Kyle Hackney and Ronda Peterson for taking time out of their hectic schedules to be a part of my thesis committee. The contributions of their expertise were greatly appreciated and shaped my thesis into what it is today.

I cannot thank Jennifer Longo enough for her flexibility, help, hard work, and dedication throughout the data collection and thesis process. I also want to thank Nate Dicks for his expertise and help throughout this process. I would like to thank Anna Bratsch and Rebekah Rye for their support and guidance through not only graduate school but also through being a newly certified athletic trainer. I would not be the athletic trainer I am today without their willingness to help me grow and learn.

Thank you to all my participants for your willingness to participate in this study. Lastly, I would like to thank the Department of Health, Nutrition and Exercise Science and the College of Human Development and Education for their financial support. I appreciate the support they gave me to make my thesis possible.

TABLE OF CONTENTS

ABSTRACT	iii
ACKNOWLEDGEMENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	viii
1. INTRODUCTION	1
1.1. Overview of the Problem	1
1.2. Statement of Purpose.....	1
1.3. Research Questions	2
1.4. Definitions	2
1.5. Limitations	3
1.6. Delimitations	3
1.7. Assumptions.....	4
1.8. Variables.....	4
1.9. Significance of the Current Study	4
2. LITERATURE REVIEW	6
2.1. Introduction	6
2.2. History of CPR.....	7
2.2.1. 2000 American Heart Association CPR Guidelines.....	8
2.2.2. 2005 American Heart Association CPR Guidelines.....	12
2.2.3. 2010 American Heart Association CPR Guidelines.....	14
2.2.4. 2015 American Heart Association Guidelines	20
2.3. Rescuer Fatigue	22
2.3.1. Compression-only CPR.....	22
2.3.2. Identifying Fatigue	23

2.3.3. Gender Differences in Performance	25
2.3.4. Compression Cycle Differences	27
2.3.5. Body Composition of the Rescuer.....	30
2.3.6. Overall Strength of the Rescuer	32
2.4. Conclusion.....	35
3. METHODOLOGY	37
3.1. Purpose of the Study	37
3.2. Participants	37
3.3. Documentation	38
3.4. CPR Performance.....	38
3.5. Statistical Analysis	40
3.6. Conclusion.....	40
4. RESULTS	41
4.1. Demographics.....	41
4.2. CPR Quality Compared to BMI and Hand Grip Strength.....	42
4.3. Subjective Fatigue Levels	44
5. DISCUSSION.....	48
5.1. Quality of CPR Performance Between Protocols	48
5.2. Comparing BMI and Hand Grip Strength to CPR Performance.....	50
5.3. Comparing BMI and Grip Strength with Self-Reported Fatigue	52
5.4. Comparing Self-Reported Fatigue Levels Between Protocols.....	54
5.5. Limitations	56
5.6. Future Research.....	57
5.7. Conclusions	58
REFERENCES	59

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Time delays for carotid pulse checks.....	11
2. Comparison of 2005 and 2010 CPR Guidelines after eight minutes.....	16
3. Physiological response to performing five minutes of CPR (mean \pm standard deviation)	24
4. Comparison of genders when performing standard and continuous CPR.....	26
5. Comparison of depths and total compressions between both types of CPR after eight minutes.....	27
6. One-minute and two-minute cycle groups' CPR performance after four minutes	28
7. Compression rate, depth, and total number of compressions after 10 minutes of CCC	30
8. Comparison of the components of 30:2 CPR and continuous chest compressions after performing for 10 minutes.....	34
9. Participant demographics (mean, standard deviation, minimum, and maximum)	41
10. Hand grip strength (measured in kilograms)	42
11. CPR quality for 30:10 session	42
12. CPR quality for continuous compression session.....	43
13. Comparing RPE scores for both compression-only CPR protocols	47

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Subjective fatigue levels during CPR sessions	45
2. Number of breaks taken during continuous compressions CPR.....	45

1. INTRODUCTION

1.1. Overview of the Problem

Cardiac arrest affects approximately 6 million people in the world each year with 295,000 of those cases occurring in the United States.^{1,2} One of the medical interventions used to increase survivability of cardiac arrest is cardiopulmonary resuscitation (CPR) delivered by a bystander. Chest compressions continue blood flow to the heart and brain while assisting the heart in obtaining a shockable rhythm and increase the possibility of favorable neurological outcomes. The American Heart Association (AHA) has recently suggested lay rescuers, those individuals who are not allied health care providers, perform compression-only CPR, which consists of chest compressions without the rescue breaths. Compression-only CPR may be more effective than the traditional ratio of compressions to ventilations according to recent research and the AHA Guidelines. Continuous chest compressions allow for no interruptions and increases the benefits of chest compressions. The negative effect of continuous chest compressions is increased fatigue in the rescuer, which ultimately may decrease the effectiveness of the chest compressions.³

Bystanders and the general public are often the first responders to a cardiac arrest event and must initiate CPR to increase the patients' survival. Bystanders perform CPR for long periods of time waiting for more qualified personnel to arrive and take over, which increases the strain on the rescuer. Adding extra rest time between cycles of chest compressions may decrease the amount of fatigue felt by the rescuer and, in turn, increase the survival of the patients.³⁻⁵

1.2. Statement of Purpose

The purpose of this research study was to analyze effectiveness of continuous chest compressions during two different protocols: 30 compressions:10-second break (30:10) and as many compressions as possible with a 10-second break whenever the participant chose to take

the break(s). The secondary purpose was to evaluate rescuer fatigue through both subjective reporting and musculoskeletal strength measured with hand grip dynamometer.

1.3. Research Questions

Q₁-What is the relationship among participant traits (Body Mass Index [BMI] and average hand grip strength) and performance on dependent variables (depth %, depth mm, and chest recoil)?

Q₂-What is the relationship between participant traits (Body Mass Index [BMI] and average hand grip strength) and self-reported fatigue at the nine-minute time point for the 30:10 and continuous compressions protocols?

Q₃-What is the difference between reported fatigue levels at three, six, and nine minutes of CPR performance when comparing 30:10 and continuous compressions protocols?

1.4. Definitions

Definitions of cardiac arrest and cardiopulmonary resuscitation vary between research studies, which makes comparing the results difficult. In order to avoid confusion, the following definitions were used in this study:

Cardiac arrest: According to the American Heart Association (AHA), cardiac arrest is defined as an “abrupt loss of heart function in a person who may or may not have diagnosed heart disease”.⁶

Cardiopulmonary resuscitation: CPR, specifically the chest compressions, increases the blood flow to the heart and brain, assists the heart transition into a shockable rhythm, and increases the possibility of favorable neurological outcomes of a cardiac arrest event.³

Quality of CPR: Quality of CPR, for this study, was defined as proper chest compression depth and proper chest recoil. The measurements used to assess breaths were not used for this study as they are not performed during continuous chest compressions.

Fatigue: Rescuer fatigue decreases adequate chest compression rate and depth as well as improper chest recoil. The signs of fatigue and ineffective chest compressions begins within the first one to two minutes of CPR. Prolonged chest compressions, especially continuous chest compressions, increases the level of fatigue experience by the rescuer.⁷⁻¹⁰

Continuous Compressions: Continuous chest compressions minimize the interruptions between compressions by performing compressions without ventilations.

1.5. Limitations

Limitations of this study may affect the strength of the results. The first limitation was related to the CPR courses the participants have participated in the past. We accounted for variations in previous training by reviewing how to perform proper CPR followed by one minute of practice on the QCPR Anne Resusci Anne with feedback. An additional limitation may be physical activities the participants participated in before or after the testing sessions. We accounted for this by informing the participants of the risks of participating in other physical activities such as increased fatigue during testing and potentially skewing the data.

1.6. Delimitations

Due to the length of this study, some factors were not assessed during data collection and analysis. These variables include diet and experience level. These factors have been assessed in previous research and are outside the scope of the current study.

Interrupting CPR decreases the chances of survival of a patient suffering from cardiac arrest. The AHA emphasizes minimizing interruptions as much as possible.^{8,11,12} The two

protocols were selected based on the current compressions to ventilations ratio (30:2) and performing continuous chest compressions until they experienced fatigue and need a 10-second break and then must continue performing compressions until the end of the eight minutes and 59 seconds.

1.7. Assumptions

Based on the nature of the study, some assumptions were made about the participants and their performance. They were informed of the increase of fatigue if participated in any physical activity after performing CPR. Physical activity outside of the testing sessions may decrease their performance quality for the second day of CPR. Food and fluid intake levels in-between sessions were not recorded, which could affect fatigue levels for the second day of data collection. The final assumption was reviewing the CPR guidelines and performing the practice session would aid the participants in performing adequate CPR.

1.8. Variables

The independent variables during this study were the two protocols. The two dependent variables were compression depth and chest recoil. The subjectively reported dependent variable was rate of perceived exertion (RPE). Covariates for this methodology included gender, BMI, and hand grip dynamometry.

1.9. Significance of the Current Study

Out-of-hospital cardiac arrest events most often occur with a witness present. Bystanders, or the witness, are typically the first people to arrive on the scene and must perform life-saving CPR to the victims suffering from cardiac arrest. Evolution of the most effective and life-saving CPR continues to evolve as researchers explore every aspect of CPR. The most recent research shows continuous chest compressions to be more effective than a ratio of compressions and

ventilations. Research is needed to understand the most effective form of continuous chest compressions without exhausting the rescuers. This research study was conducted in order to distinguish a possible best practice to decrease fatigue in lay rescuers while increasing the effectiveness of the chest compressions.

2. LITERATURE REVIEW

2.1. Introduction

Cardiac arrest affects approximately 6 million people in the world each year with 295,000 of those cases occurring in the United States.^{1,2} The terms sudden cardiac death and cardiac arrest are often used interchangeably even though the definitions are starkly different. According to the American Heart Association (AHA), cardiac arrest is defined as an “abrupt loss of heart function in a person who may or may not have diagnosed heart disease”.⁶ In contrast, Chugh et al.^{13(p217)} defined sudden cardiac death as “a sudden arrhythmic death” that is from a “sudden, unexpected pulseless condition of cardiac etiology”.^{13(p214)} In order to be classified as sudden cardiac death, the event must be witnessed by another individual within an hour of the onset of symptoms or be observed alive within 24 hours of the death.¹³ Knowing the difference between cardiac arrest and sudden cardiac death is important as it determines if life-saving measures are needed for cardiac arrest.

Providing quality cardiopulmonary resuscitation (CPR) increases the survivability for a patient suffering from cardiac arrest.^{14,15} CPR, specifically chest compressions, increases the blood flow to the heart and brain, assists the heart in transitioning into a shockable rhythm, and increases the possibility of favorable neurological outcomes of a cardiac arrest event. Although CPR has always included a combination of compressions and ventilations, recent research indicates compression-only care may be more effective for lay public to provide to victims. Continuous chest compressions may increase the survivability of cardiac arrest by decreasing the interruption time and increasing the benefits of chest compressions.³ Improving coronary perfusion, defined as blood flow to and within the coronary arteries of the heart, may be

attainable with uninterrupted chest compressions.⁴ As treatment time increases, the adequacy of continuous chest compressions decreases while the fatigue of the rescuer increases.³

Cardiac arrest events that occur outside of the hospital are often witnessed by a bystander. Thus, CPR is most often performed by bystanders and members of the general public, also known as lay rescuers.^{3,16} Lay rescuers have to perform CPR for extended periods of time before more qualified personnel arrive on the scene. Performing CPR for an extended period of time increases the workload on the rescuer, which also increases the amount of fatigue of the rescuer. According to recent research, fatigue begins to affect the rescuer before the rescuer is able to detect it.^{4,5} When the rescuers experience fatigue, the effectiveness of chest compressions is compromised and ultimately effects the survival rates of patients who suffer from a cardiac emergency. Adequate CPR performance is vital to the survival of patients suffering from cardiac arrest, but when the rescuer becomes fatigued, the life-saving efforts become less effective.³

2.2. History of CPR

The evolution of the components of cardiopulmonary resuscitation have been documented since its inception over 150 years ago. The way to properly perform chest compressions described today is similar to the description by John Hill in 1868 when he observed a restoration in heart rhythm when a force was applied to the chest. External chest compressions were first documented by Boehm but were abandoned due to the growing popularity of internal chest compressions, which are performed directly to the heart when the chest is open. In 1957, William Kouwenhoven and his colleague Guy Knickerbocker rediscovered external chest compressions after noticing a pulse when defibrillator pads were forcefully placed on animals. As a result of this discovery, they began performing external chest compressions, which produced circulation in dogs suffering from cardiac arrest. Human clinical

trials of performing chest compressions were conducted by James Jude who collaborated with Kouwenhoven and Knickerbocker, and the successful results were published by Kouwenhoven in 1960.^{17,18} External chest compressions began to take precedence over internal chest compressions and would later lead to the benefits of rescue breaths also being discovered.

Although the current trend in performing CPR is to concentrate on compressions, rescue breaths were originally part of the CPR algorithm. In addition, rescue breaths are still encouraged for allied health care workers providing CPR. Peter J. Safar revealed the ability to regain tidal volume when the airway of the patient was aligned, and air was expired from the rescuer into the mouth of the patient. He realized chest compressions alone could not produce enough tidal volume in the lungs because of the blocked airway due to jaw malalignment. Safar combined the airway alignment, rescue breaths, and chest compressions, which is now known as the ABC of CPR.¹⁷ All these components of CPR are critical pieces of the overall care cardiac arrest patients need in order to survive.

2.2.1. 2000 American Heart Association CPR Guidelines

Prior to the publication of the 2000 American Heart Association (AHA) CPR Guidelines, lay public and health care professionals were advised to perform five chest compressions and one ventilation (5:1) during two-person rescuer CPR. In order to explore the idea of changing the recommended compressions to ventilations ration, researchers recruited 17 paramedic students to test the difference between a methodology of 5:1 for two rescuer CPR and 15:2 for one rescuer CPR. The sequences of CPR were performed on an Ambu Mega Code Trainer, which recorded aspects of CPR including ventilations, chest compressions, carotid pulse, ECG simulation and defibrillation. Two cameras from different angles recorded the rescuers' performance during the CPR sessions. Each CPR session was randomly assigned to two participants where each person

would alternate between rescuer one and rescuer two positions. Ten rounds of 5:1 CPR and four rounds of 15:2 CPR were referred to as one loop by the researchers. CPR was performed in cycles of 60 seconds with 15 seconds for a break to complete other tasks. The cycle was continued until the tasks such as ECG interpretation, intubation, IV cannulation, and administering necessary medications were performed. Once all these tasks were performed, the manikin's rhythm switched from asystole to ventricular fibrillation. The tasks were performed by rescuer 1 between ventilations or during 15-second pauses between ventilations and compressions without interfering with the ECG analysis while rescuer 2 performed the 5:1 CPR. During 15:2 CPR, rescuer 1 executed all the tasks while rescuer 2 performed CPR.¹⁹

After all the data had been collected, independent two-tailed t-test and Fisher's exact test were used to assess the output. Less CPR loops were performed during the 15:2 CPR (median= 1.75) as compared to the 5:1 CPR (median= 3). When 15:2 CPR was performed, three manikins were in sinus rhythm after the first loop ($p= 0.229$) and all manikins were in sinus rhythm after the second loop. However, none of the manikins were in sinus rhythm after the first loop of 5:1 CPR and only five manikins were in sinus rhythm after the second loop. There was no statistically significant difference in the quality of CPR performed between the two sessions despite the 15:2 group having more manikins in sinus rhythm. When 15:2 CPR was performed, the rescuers were able to complete the tasks in a faster time than the 5:1 CPR. The recording of the CPR performance of both sessions portrayed more stress and demand on the rescuers performing 5:1 CPR. More series of 5:1 CPR went without any ventilations due to the completion of tasks as compared to the 15:2. The 15:2 CPR ratio allowed more time for the rescuers to perform other life-saving tasks and was less demanding than 5:1 CPR.¹⁹ Following an analysis of patient outcomes similar to the aforementioned research, the American Heart

Association (AHA) and the European Resuscitation Council recommended an increase in the number of compressions (15) and ventilations (2).¹⁹⁻²¹

Before the 2000 AHA CPR Guidelines were published, the last step of an initial evaluation during a cardiac arrest event was to determine the patient's circulation, which is assessed by palpating the carotid pulse and observing for any response to the rescue breaths administered such as coughing, movement, or normal breathing. Sixteen patients undergoing coronary artery bypass surgery were used in a study to determine the accuracy of lay rescuers identifying a pulse. These patients were selected for intraoperative examinations by four groups of first responders. The first responders consisted of EMT-1 (n= 107), laypersons or EMT students who did not have advanced training but passed the Basic Life Skills course; EMT-2 (n= 16), EMTs who have completed the four weeks of theoretical and six weeks of practical instruction, PM-1 (n= 74), paramedics in training; and PM-2 (n= 9), completed the two-year course. Participants were exposed to two different scenarios in which they were expected to palpate a carotid pulse. The first scenario was spontaneous circulation as a result of mobilization of the internal mammary artery, which had a systolic pressure greater than or equal to 80 mmHg for 30 minutes. The second scenario was no pulse with the aorta cross-clamped and the arterial and venous pulselessness was at a mean arterial pressure between 50 and 80 mmHg. The rescuers were instructed to assess the patient for an absent or present pulse as soon as they could within five to 10 seconds according to the AHA Guidelines. The diagnosis given by the participant was compared to the actual pulse of the patient during the assessment.²²

Statistical analysis was conducted to determine the delay and accuracy of the pulse check readings. Percentiles were determined for each second of delay of the pulse check up to one minute. A comparison between the four groups was performed using Mann-Whitney and

Kruskall-Wallis. The accuracy was calculated using a percentage of the correct diagnoses among all assessments. The sensitivity and specificity of the carotid pulse check for pulselessness was computed and an independent t-test compared the blood pressure and heart rate between groups. A total of 206 participants performed pulse checks of which 147 assessments had a pulse and 59 assessments were pulseless. Pulselessness was not recognized within 60 seconds in 10% of the diagnoses. A diagnosis of no pulse was recorded a total of 45% of the 147 present pulses, despite a pulse being present at a radial arterial systolic pressure of more than 80 mmHg. The sensitivity for central pulselessness was almost 90% but the specificity was 55%. The sensitivity and specificity did rise, however, as the level of emergency medical training increased. The level of training had a statistically significant effect on a shorter delay in diagnosis ($p < 0.005$).²²

Table 1. Time delays for carotid pulse checks

Pulse Checks	Median Time Delay	Delay Range
No pulse	32 seconds	12-60 seconds
With a pulse	22 seconds	3-55 seconds
Total	24 seconds	

Table 1 displays the time delays the participants took when attempting to locate a carotid pulse. Only 16.5% of the participants were able to reach a diagnosis within the 10 seconds but three participants of the 16.5% incorrectly diagnosed a patient as pulseless instead of having a pulse. Only one participant was able to correctly diagnose the patient as pulseless within 10 seconds. The results of this study indicate the difficulties of diagnosing patients with a pulse or without a pulse. Due to the inaccuracy of pulse checks in lay rescuers as determined in research, the pulse check has been eliminated from the guidelines for lay rescuers.²²

In summary, there were changes in the recommendations for the performance of CPR and the assessment of cardiac arrest issued by the AHA in the 2000 CPR Guidelines. Two rescuer

CPR changed from a ratio of 5:1 to 15:2 in order to provide more compressions and decrease over-ventilation. Finally, the lay public was encouraged not to waste time palpating a carotid pulse as the assessment was often inaccurate. Evidence-based guidelines continued to be tested as advancements in medical research have been published.

2.2.2. 2005 American Heart Association CPR Guidelines

The 2005 American Heart Association Guidelines CPR Guidelines Part 4: Adult Basic Life Support¹² changed the compression to ventilation ratio from 15 compressions and two breaths (15:2) to 30 compressions and two breaths (30:2). The guidelines state, “This 30:2 ratio is based on a consensus of experts rather than clear evidence.”^{12(pIV-26)} The consensus was made because the new ratio allowed for an increase in the number of compressions per minute, decreased over-ventilation of the patient, minimized interruptions, and simplified instructions for teaching and retention.¹² The change was supported by a study comparing the two different ratios of chest compressions and rescue breaths with 18 basic life support-certified healthcare providers. Fifteen chest compressions to two breaths (15:2) and 30 chest compressions to two breaths (30:2) were performed for five minutes in two different sessions. No flow time, which is the amount of time without chest compressions, was compared during the two sessions. The heart rate, capillary lactate, and Rate of Perceived Exertion (RPE) were recorded before and after each session. During each session, feedback was given to the participants through the QCPR Resusci Anne manikin feedback technology. A repeated-measures ANOVA was calculated showing statistical significance of 30:2 CPR having more compressions per minute ($p= 0.007$) and a lower no flow time than 15:2 ($p< 0.001$). There was no statistical significance between the two different ratios when comparing depth, rate, and chest recoil.¹⁰ Lower no flow time and

increased number of chest compressions per minute increases the rate of survival for patients suffering from cardiac arrest.

Similar to the previous study, 50 career paramedics completed three sessions of CPR for 10 minutes. The purpose of the study was to determine if the quality of CPR decreases when the workload and the number of chest compressions per minute were increased. The researchers chose three ratios of CPR: 15:2, 30:2, and 50:2 to test the theory and randomly assigned participants to each session. Each session was separated by 25 minutes of rest or until the paramedic felt ready to complete the next session. The mean compression depth and rate, the number of compressions, and the no flow time were recorded. The total number of chest compressions after the 10 minutes increased significantly from 604 with the 15 compressions ratio, 770 with the 30 compressions ratio, and 862 with the 50 compressions ratio. The compression rate was higher in the 15:2 (118 ± 18) ratio when compared to the 30:2 (115 ± 18) and 50:2 (112 ± 16) ratios ($p < 0.02$ and $p < 0.0005$). There was no statistical difference, however, in the compression depth when compared between all three scenarios.²³

In the 2005 AHA CPR Guidelines, experts recommended an increase in chest compressions from 15 to 30. A study consisting of 68 participants focused on the quality of CPR for 15:2, 30:2, and continuous chest compressions. Each participant would randomly select an inverted sheet marked 15:2, 30:2, or continuous chest compressions. No instructions were given on how to perform CPR or any feedback given during the performance. There was no difference in compression depth between 15:2 and 30:2, and the compression depth stayed within the European Resuscitation Council guidelines which was a depth of 4-5 cm. The compression depth was lower in the continuous chest compressions ($30 \pm 8\text{mm}$) than 15:2 (41 ± 11 , $p < 0.05$) and 30:2 (45 ± 8 , $p < 0.05$). The compressions per minute were higher with continuous chest

compressions with 73 ± 24 compared to 15:2 (40 ± 9) and 30:2 (43 ± 14) but no p-value was reported. More ventilations were given per minute during 15:2 CPR (3.1 ± 2.4) than 30:2 (1.6 ± 1.4) ($p < 0.05$). However, no flow time percentage was higher in the 15:2 group ($49 \pm 13\%$) than the 30:2 ($38 \pm 20\%$) ($p < 0.05$). The no flow time for continuous chest compressions ($1 \pm 2\%$) was less than both 15:2 ($49 \pm 13\%$, $p < 0.05$) and 30:2 ($38 \pm 20\%$, $p < 0.05$). The statistical analysis of the data confirms the 30:2 ratio decreases the amount of time dedicated to ventilations.²⁴ The decrease in time for ventilations increases the amount of chest compressions delivered to a patient suffering from cardiac arrest, which likely increases the survivability.

In addition, there was a renewed focus on the quality of compressions given to victims. It was still recommended to issue 100 compressions per minute at a depth of one and a half to two inches (1.5- 2) for an adult. The chest recoil, which allows the blood to return to the heart, was emphasized in these guidelines to allow for complete recoil and ensure equal compression and relaxation times. Finally, lay rescuers who were unwilling or unable to perform rescue breaths, were encouraged to perform compression-only CPR.¹²

2.2.3. 2010 American Heart Association CPR Guidelines

The 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Part 5: Adult Basic Life Support¹¹ reported 30 compressions to two breaths (30:2) was still the recommended ratio to perform CPR. As previously stated in the 2005 AHA CPR Guidelines, this recommendation was based on a consensus made by experts but additional case series were published since 2005 confirming the change.¹¹ Also similar to the 2005 AHA Guidelines, the 2010 AHA Guidelines emphasized pushing fast, hard, and without interruptions.²⁵ There was a change in the sequence of actions taken following a cardiac arrest from airway-breathing-circulation (A-B-C) to circulation-

airway-breathing (C-A-B). Experts prioritized the initiation of chest compressions before assessing other body systems, such as adequate breathing.^{11,26} Once an advanced airway was placed, two rescuers continued delivering chest compressions at 100 compressions per minute and delivering rescue breaths every six to eight seconds, or eight to 10 each minute. The ratio of chest compressions to ventilations (30:2) did not change from 2005 to 2010, but the sequence of actions changed as well as the rate of compressions.¹¹

Chest compression depth was altered in the 2010 AHA CPR Guidelines to allow the heart to be completely compressed and the blood to fully reach vital organs. The chest should be depressed at least two inches in the 2010 Guidelines instead of the previously recommended one and a half to two inches in the 2005 AHA CPR Guidelines. Researchers investigated the change in compression depth with 81 participants who were randomly assigned to the group performing the 2005 AHA CPR Guidelines depth of 38 mm to 50 mm (1.5 to 2 inches) or to the group performing the 2010 AHA CPR Guidelines depth of greater than 50 mm (2 inches). The quality of chest compressions was assessed by recording mean chest compression depth every minute, number of appropriate chest compressions depth and chest compressions at a depth greater than 38 mm every minute, compression rate every minute, incomplete chest recoil, and abnormal hand placement. The chest compressions were performed for eight minutes total. Fatigue levels were assessed through heart rate and blood lactate levels before, during, and after the performance of the chest compressions. Table 2 displays results of the data analysis between the 2005 and 2010 AHA CPR Guidelines and fatigue levels.²⁷

Table 2. Comparison of 2005 and 2010 CPR Guidelines after eight minutes

CPR characteristic	2005	2010	P-value
Number of chest compressions at proper compression depth	28 ± 44	8 ± 24	< 0.05
Number of compressions with a depth of greater than 38mm	34 ± 48	60 ± 57	< 0.05
Heart rate post CPR (beats/min)	103 ± 12	116 ± 15	< 0.01
Lactate levels post CPR (mmol/L)	2.7 ± 0.8	3.6 ± 1.0	< 0.01

The recommendation to increase the depth of compression increased the rate of compressions (34 ± 48 compared to 60 ± 57) but also increased fatigue in the rescuer based on the heart rates, blood lactate levels, and RPEs. The overall compression rate increased but the number of compressions achieving a two-inch depth decreased. Heart rate and lactate levels were elevated after eight minutes of performing the 2010 CPR Guidelines. The 2010 AHA CPR Guidelines emphasized a chest compression depth of two inches to allow for a fully compressed heart and increase blood flow to the brain and lungs. The increased compression depth increases the physical demands of CPR on the rescuer including fatigue, heart rate, and blood lactate levels.²⁷

The 2010 CPR Guidelines emphasized minimizing any interruptions during the performance of CPR as well as between cycles. Minimizing interruptions increases the survival of the patient because it allows for more time to administer CPR. An observational study of in-hospital and out-of-hospital cardiac arrests was conducted between March 2002 and December 2005. Exclusion criteria were any patients who suffered cardiac arrest in the emergency department or operating room or if the monitor used in the study was not applied to the patient. Thirteen patients were excluded from the study because there were technical difficulties or chest

compressions were not started before a shock was administered. A total of 60 patients were included in the study where an investigational monitor was used to measure the chest compression rate, compression depth, ventilation rate, ventilation volume and the presence of a pulse. The chest compressions were assessed through the chest compression pad with an accelerometer and force detector. Ventilations and pulses were assessed through changes in the chest wall impedance. Measurements were assessed and recorded every 30 seconds and any pauses were evaluated by two physicians. The outcomes of the patients after the cardiac arrest were obtained through medical records.²⁸

Statistical analysis of the 60 patients were obtained through a t-test, a chi-squared analysis, and a logistic regression analysis. Successful shocks from an AED were associated with shorter median pre-shock pauses (11.9 seconds versus 22.7 seconds, $p= 0.002$) and increased mean chest compression depth (39 ± 11 mm versus 29 ± 10 mm, $p= 0.004$). There was no statistical difference determined between-groups with the variables of ventilation rates, chest compression rates, and no flow time. If the first shock was successful, the patient was more likely to have return of spontaneous circulation time during the treatment (55% versus 25%, $p= 0.004$) and an increased chance of survival to discharge despite no calculated statistical significance (9% versus 0%, $p= 0.21$). When pauses pre-AED shock and compressions met the recommended depth, both in-hospital and out-of-hospital cardiac arrest events resulted in favorable patient outcomes.²⁸

In 2010, the AHA implemented significant revisions to the CPR Guidelines to combat ineffective performance of CPR in out-of-hospital cardiac arrest events. These new Guidelines emphasized lay rescuers performing compression-only CPR instead of chest compressions with rescue breaths. If a lay rescuer is unable to or unwilling to perform rescue breaths, he or she

should at the very least perform chest compressions. A cohort study was performed examining out-of-hospital cardiac arrests for patients over the age of 18 from May 1, 1998 to April 30, 2003. The type of CPR (no CPR, standard 30:2 CPR, or continuous chest compression CPR) was recorded by EMS at the time of the incident, and then the survivors were followed one year after the event to assess the neurological outcomes. A repeated measures-ANOVA and X^2 test were computed to analyze categorical variables, a logistic regression was used to analyze the relationship between the types of CPR performed and the outcomes of the survivors, and an odds ratio and 95% confidence interval were conducted as well. A total of 13,444 cases occurred out-of-hospital but only 4,902 of the reported OHCA events were witnessed. Of those 4,902 cases, 783 patients (16%) received standard 30:2 CPR, 544 patients (11%) received continuous chest compressions, and 25 received no CPR at all. More favorable neurological outcomes were present in both the chest compression-only (3.5%) and standard CPR groups (3.6%) compared to no CPR (2.1%). There was also a higher survival rate one year after the incident in both CPR groups (compression only- 95% CI: 1.01- 2.95; standard CPR- 95% CI: 0.95- 2.60) compared to when no CPR was performed. No difference was determined between performing standard or compression-only CPR, which suggests compression-only CPR being as effective as standard CPR.¹⁴

A longitudinal study was conducted using 1,151 patients who received a type of resuscitation effort following cardiac arrest. Four hundred thirty-nine (11%) received continuous chest compressions, 712 (18%) received standard CPR, and 2,917 (72%) did not receive any CPR. Bystander resuscitation efforts, such as compression-only, standard, pulmonary-only, unidentified (included any changes in technique), and undocumented cases, were categorized and recorded by the paramedics upon arrival. Favorable neurological outcomes were assessed 30

days after the cardiac event according to the Glasgow-Pittsburgh cerebral performance categories.¹⁵

Statistical analysis of the data consisted of an X^2 test for the baseline categorical measurements and a Mann-Whitney U for the continuous measurements. The relationship between favorable neurological outcomes and the time between the attempts of CPR and first using an automated external defibrillator (AED) were assessed using a non-linear regression analysis. Continuous chest compressions had a higher number of patients with favorable outcomes than standard CPR when the patients had apnea ($p= 0.0195$), ventricular fibrillation or tachycardia ($p= 0.041$) and when CPR was started within four minutes of the cardiac arrest ($p= 0.0221$). Continuous chest compressions also resulted in more favorable neurological outcomes than standard CPR (95% CI: 1.2–4.9; $p= 0.0086$). The researchers concluded continuous chest compressions were comparable or even more effective than standard CPR. Victims who received a combination of compressions and ventilations had more favorable neurological outcomes than no CPR, but the chest compression-only CPR showed increased favorable outcomes in certain subcategories.¹⁵

It is still recommended healthcare providers provide two rescue breaths after 30 compressions and maintain that ratio until an advanced airway has been placed. The rescue breaths should continue to be delivered over one second every six to eight seconds producing a visible chest rise. Once an advanced airway is placed, rescue breaths are given in the same manner with one breath every six to eight seconds without any pause in chest compressions.¹¹ The AHA began to discover the inaccuracy of performing rescue breaths for lay rescuers and made a significant change to the CPR guidelines in 2010 by taking the rescue breaths out of CPR.

2.2.4. 2015 American Heart Association Guidelines

The 2015 AHA CPR Guidelines⁸ changed the chest compression rate instructions, stating the chest compression rate should be raised to 100-120/min instead of the 100/min as dictated in the 2010 AHA CPR Guidelines. The Guidelines outlined the reasoning behind the increase because the more chest compressions performed per minute is associated with favorable neurological outcomes, an increase in the return of spontaneous circulation, and higher survival rates. The addition of the maximum rate is to keep rescuers from compressing too fast without compressing deep enough.⁸

Chest compression depth allows the heart to be fully compressed during CPR, but it also must be permitted to replenish the heart with blood on the relaxation phase. Rescuers are to depress the chest a minimum of 2 inches but not exceed 2.4 inches. The limit is to avoid any injuries to the victim that may be sustained through the performance of CPR. The AHA still placed a limit on the depth of compressions to make the rescuer aware of potential risks of compressing too deep.⁸ Researchers investigated the proper chest compression depth using nontraumatic cardiac arrests in individuals over the age of 18. An accelerometer interface between the patient's chest and the rescuer was placed using defibrillators. Chest compression rate, fraction and depth were calculated using the proprietary automated external defibrillator analytic software. During June 2007 and October 2010, 9,136 patients experienced cardiac arrest and were included in the study. More patients survived to hospital discharge when the depth was greater than 51 mm (1530 deaths, 138 survivors; $p < 0.001$). Those who survived cardiac arrest were administered chest compressions in the adequate depth range for a longer percentage of time (69%) than those that did not survive (61%) ($p < 0.001$). The proper depth of chest compressions increases the survivability of patients who are suffering from cardiac arrest.²⁹

When CPR is performed, the chest should be allowed to be recoil and relax fully before compressing again. The 2015 AHA Guidelines reemphasized full chest recoil during chest compressions similar to the 2010 AHA Guidelines. The rescuer should avoid leaning on the patient as this does not allow full recoil of the chest. CPR requires a balance of compression depth and full chest recoil to provide life-saving measures.⁸

Utilizing an AED as soon as possible adds to the favorable outcomes of resuscitation and increases the chance of the patient's heart returning to a normal rhythm. Researchers randomly assigned 993 community units (apartment buildings, shopping malls, hotels, residential areas, etc.) where lay public in the areas were to perform CPR only or CPR and administering an AED during a cardiac arrest event. The community units were observed by the researchers during July 2000 and September 2003. The purpose of the study was to determine which intervention increased the survival to hospital discharges. Each AED was inspected monthly to ensure it was functioning properly. The term cardiac arrest was used when more than two ventilations or more than five chest compressions were performed on the patient. The lay rescuers were notified of potential cardiac arrest events through various means such as overhead paging and notifications through security. Twice as many patients survived to discharge in the CPR and AED units (31) than the CPR only units (16) ($p= 0.03$, 95% CI= 1.07-3.77). When an AED is applied to a patient suffering from suspected cardiac arrest, the survival to hospital discharge is greater than CPR alone.³⁰ There should also be little to no interruptions for the chest compressions even while applying the AED. It was now recommended to shock a patient as soon as possible if an automatic external device (AED) is readily available as opposed to initiating CPR first. Using an AED as soon as possible, allowing full chest recoil, and minimizing interruptions during chest compressions increases the effectiveness of resuscitation efforts.⁸

2.3. Rescuer Fatigue

In 2015, the AHA CPR Guidelines changed the procedures for untrained bystanders as a means to increase the survival rates of cardiac arrest patients. The change instructed lay public to apply continuous chest compressions instead of the 30 compressions and two breaths procedures as dictated in the 2010 AHA CPR Guidelines. These updated Guidelines state 100 continuous compressions per minute for lay rescuers is the best intervention for the survival rate of a cardiac arrest even when the rescuer is not trained or confident in giving rescue breaths.^{4,8} These 100 compressions should be performed with no breaks and should be performed fast and hard.^{3,16,31} Compressions are to be performed at a minimum depth of two inches (or 5 cm) in adults.^{3,5} Due to these criteria, performing 100 compressions per minute causes rescuer fatigue faster than the 2005 AHA guidelines of 30 compressions to two ventilations.^{3,16,32}

2.3.1. Compression-only CPR

Compression-only CPR causes fatigue for rescuers than standard CPR due to the physical stress of continuous compressions. Shin et al.³³ studied 96 medical students (n= 49) or physicians (n= 47) who performed CPR for eight minutes while measuring rate and number of compressions as well as heart rate of the participants. Two different scenarios of CPR were randomly assigned to each participant where the group of rescuers were either switched by a stopwatch (RC2) or switched by a leader (RCL). The leader was instructed to watch for signs of fatigue in rescuers and once they became present, the rescuers would be switched. The chest compressions were performed continuously due to the patients having an advanced airway placed before compressions started. The mean depth of compressions was decreased in RC2 than RCL (49.5 ± 4.7 versus 52.6 ± 3.8 ; $p= 0.002$). Fewer rescuer changes and interruptions in CPR occurred in the RC2 group than the RCL group (3 versus 6.5 ± 1.4 , $p< 0.0001$; 14.8 ± 1.0 versus 21.3 ± 2.6 ; $p<$

0.0001). The rate of chest compressions, proportion of incomplete chest recoil, or abnormal hand positions were not statistically different between groups. Shin et al.³³ reported the rate and number of quality chest compressions were lower when participants performed continuous chest compressions of 100-120 compressions per minute versus the standard CPR practice of 30 compressions to two breaths. No statistical difference was determined in the total number of chest compressions between the two groups, but there was a decrease every minute for correct chest compressions in the RC2 group ($p= 0.001$). According to the results of this study, leaders who have extensive experience in CPR are able to identify fatigue and switch rescuers to provide more effective CPR than a timed cycle. Continuous chest compressions increase the fatigue of rescuers, but if a leader is able to identify fatigue in rescuers, it will decrease the amount of fatigue in the rescuer and increase effective CPR.³³

2.3.2. Identifying Fatigue

According to current research, rescuers do not adequately identify when they begin to experience the effects of fatigue and therefore diminish the quality of compressions. Ock et al.³⁴ conducted a study with 47 participants (25 male, 22 female) who performed CPR for five minutes on a manikin. The physical fitness level of each participant was assessed using maximal aerobic exercise capacity with VO_2 max, muscle strength, muscle power, muscle endurance and agility. The researchers computed a one-way ANOVA for the number of compressions and mean percentage of correct compressions. Multiple linear regression analyses were used to assess relationships between sex, weight, height, physical fitness, and correct chest compressions. Muscle strength and power was stronger and higher in males than females ($p < 0.001$) however muscle endurance and cardiorespiratory endurance were not statistically different.³⁴

Table 3. Physiological response to performing five minutes of CPR (mean \pm standard deviation)

Factors Affecting CPR	Minute 1	Minute 5	p-value
Heart rate (beats/min)	112.3 \pm 2.7	128.1 \pm 2.7	< 0.001
Percentage of estimated maximum heart rate (%)	56.7 \pm 1.3	64.8 \pm 1.4	< 0.001
Mean oxygen consumption (VO ₂ , L/min)	0.58 \pm 0.04	0.68 \pm 0.03	< 0.001
Ratings of perceived exertion	10.8 \pm 2.0	16.6 \pm 2.0	< 0.001
Mean minute ventilation volume (L/min)	14.94 \pm 0.9	21.41 \pm 1.1	< 0.001

Correct chest compressions decreased from one minute to the next when compared across all categories ($p < 0.001$). Correct compressions were defined as the proper depth of four to five centimeters. Table 3 shows the physiological responses to the five minutes of CPR for both genders. The researchers reported the participants reached 65% of the estimated maximum heart rate after performing CPR for five minutes. In this study, the researchers determined performing CPR is aerobic in nature because the volume of oxygen consumption and ratings of perceived exertion were in the aerobic phase of a maximal exercise test.³⁴ Due to this increase in physical exertion, fatigue is a major influence on the quality of chest compressions and depth of compressions.^{5,35,36}

Conflicting research has been conducted on determining if fatigue is greater during continuous chest compressions than standard CPR. In contrast to Ock et al.'s research, Riera et al.³⁷ did not find diminished quality of continuous chest compressions. The study consisted of 23 volunteers who were a part of the hospital cardiac arrest team. CPR was performed according to the 2005 European Resuscitation Council Guidelines for two minutes with compressions given at 100 per minute with no interruptions. The rate of compressions was measured every minute and any rates below 25% of the guidelines were stopped, and the two minutes were restarted after the

rescuer was given adequate time to rest. The researchers used heart rate, visual analog scale, and oxygen saturation to measure how well the participants tolerated the duration of performing chest compressions. The mean heart rates for baseline, after one minute, and after the two minutes of continuous chest compressions were 84 ± 11 , 106 ± 15 , 111 ± 13 , respectively. The participants did not surpass 80% of the theoretical maximum heart rate and the mean maximum heart rate was $61 \pm 8\%$ (range: 49.5-75.7%). No correlation was found between values of BMI and heart rate at one minute and two minutes. The mean VAS score reported was 3 ± 2 , which means the participants felt little to no discomfort.³⁷ Despite the contrasting findings of the previous two studies, two minutes of CPR was performed in the study by Riera et al.³⁷, but five minutes of CPR was performed in the study by Ock et al.³⁴ The difference in duration of CPR performance may account for the difference in fatigue levels. An ambulance, in an urban setting, takes an average of eight minutes and 59 seconds to arrive on the scene of medical emergency, which means lay rescuers must perform CPR for extended periods of time.^{38,39}

2.3.3. Gender Differences in Performance

During CPR performance, males tend to perform more effective and adequate chest compressions than females. Adequate compressions consist of proper depth and rate according to the guidelines. Researchers examined the gender differences while performing CPR using 36 first-year EMT students (m= 18, f= 18) who participated in a basic life support course for three hours. The students were grouped by gender and then randomized to perform standard CPR (30:2) or continuous compressions for eight minutes. There was a three-hour rest in-between each eight-minute CPR session. An electrocardiograph was recorded, blood pressure was taken before and after the session, and heart rate was continuously monitored during each session for all the participants. Age, height, weight, and BMI of the individuals were recorded as well. The

rate of compressions was controlled by an electronic metronome. The researchers recorded the depth and rate of compressions for each session as well as the number of compressions performed per minute during the continuous-compressions session. Researchers also recorded unsuccessful chest recoil and hands-off time taken to administer two rescue breaths during standard CPR.⁴⁰

Statistical analyses were used to compare relationships between gender and adequate chest compressions. Statistical analysis was completed using a paired t-test comparing the two sessions of CPR to find the difference in the rate of adequate chest compressions after two minutes (52 ± 45 and 41 ± 43 chest compressions, $p= 0.015$). Even though there was a difference found in the first two minutes, there was no difference when all eight minutes were combined.

Table 4 displays the results of each gender’s performance during standard and continuous CPR.⁴⁰

Table 4. Comparison of genders when performing standard and continuous CPR

Characteristics of CPR	Males (p-value)	Females (p-value)
Difference between both types	0.012	0.271
Depth greater than 5 cm of compressions	0.021	0.763
Heart rate difference between both sessions	0.015	0.021

When comparing the depth of compressions across groups, no raw data was published but the researchers reported no difference in CPR performance ($p= 0.078$). Table 5 displays the total compressions and depths of compressions between both types of CPR after the entire eight minutes were performed. There was no difference between both CPR sessions in the participants’ blood pressure and the rate of recoil. Despite the researchers not including raw data, they reported a difference in heart rate was statistically significant between the two CPR sessions ($p= 0.001$).⁴⁰

Table 5. Comparison of depths and total compressions between both types of CPR after eight minutes

Compression characteristics	Standard CPR	Continuous CPR	p-value
Total number of compressions	76 ± 10	111 ± 9	0.001
Number of compressions at more than 5 cm	29 ± 34	17 ± 36	0.024
Number of compressions at more than 4 cm	50 ± 32	41 ± 49	0.236

The researchers discovered male rescuers had an increased number of adequate compressions and a better chest compression rate when compared to female rescuers. The researchers also discussed males had an increased number of adequate compressions and a better rate than females. Males were able to continue performing adequate chest compressions per minute throughout the eight minutes of standard CPR but decreased steadily after two minutes of continuous chest compressions. Females, however, decreased in adequate chest compressions after one minute during both standard and continuous CPR. Males were able to perform more adequate compressions than females in this study but the continuous compressions were still significantly decreased in accuracy than the standard CPR.⁴⁰ Despite the male participants outperforming the female participants, they were still unable to provide effective chest compressions throughout the continuous chest compression session.

2.3.4. Compression Cycle Differences

Changes to the administration of continuous compressions, such as a change in rescuers or adding a break, helps decrease fatigue in the rescuers, which will improve the quality of compressions. A study was conducted with 39 volunteer students from a senior-grade medical school. Demographic data were recorded of each participant, which included gender, age, weight, BMI, and muscle strength with a hand dynamometer. Two sessions of CPR were

performed, which were four cycles of one-minute CPR with a one-minute rest (1-MCG) or two cycles of two minutes of CPR with two minutes of rest (2-MCG). Fifteen minutes of rest were given between each session. Fatigue was reported after the last CPR session and ten minutes after the final session. The ratios of adequate chest compressions and chest compression depth (50-60 mm) were measured. The mean compression depth, mean adequate compressions and adequate compression rate per minute were all recorded for each CPR session.⁴¹

The statistical analysis of this study was comprised of a linear mixed model, which were reported as means and 95% confidence intervals. The mean compression depth was deeper in the one-minute-cycle group (1-MCG) than the two-minute-cycle group (2-MCG) (50.67 ± 5.33 mm versus 49.44 ± 5.86 mm). A relationship was determined between hand grip strength and both mean compression depth in millimeters and mean adequate compressions ratio in percentage ($p < 0.01$ for both characteristics of CPR). Table 5 displays the differences found between both cycle groups and performance of CPR.⁴¹

Table 6. One-minute and two-minute cycle groups' CPR performance after four minutes

Comparison of characteristics of CPR	1-minute group	2-minute group	p-value
Mean compression depth (mm) compared to session	50.67 ± 5.33	49.44 ± 5.86	< 0.01
Mean compression depth (mm) compared to strength (kg)	50.67 ± 5.33	49.44 ± 5.86	< 0.01
Mean adequate compressions ratio (%) compared to strength (kg)	70.43 ± 35.85	67.56 ± 35.29	< 0.01
Mean adequate compression ratio (%) compared to strength (kg) at 4 minutes of CPR	63.69 ± 41.62	54.45 ± 42.71	< 0.01
Mean adequate compression ratio (%) compared to session	63.69 ± 41.62	54.45 ± 42.71	< 0.03

The subjective fatigue reported at the end of the cycles and the 10-minute rest was lower in 1-MCG (72.1 ± 12.07) than 2-MCG (80.18 ± 11.97). The researchers reported rescuer fatigue is reduced when the shift change occurs at one minute instead of the recommended two minutes as required by the AHA guidelines.⁴¹

Instead of rescuer groups switching according to an experienced leader, a break in-between a set amount of chest compressions may help decrease the amount of fatigue in the rescuer. Min et al.⁴² studied 63 emergency medical technician trainees who took a 120-minute training program according to the 2010 AHA Guidelines. Three different methods of CPR were performed for 10 minutes each. The first method was performing CPR continuously for the 10 minutes without a break (CCC); the second was performing CPR 200 compressions with a 10-second rest in between cycles (200/10); the third method was performing 100 compressions with a 10-second break (100/10). Each participant was scheduled for three sessions with no more than three days between sessions. Two researchers monitored the CPR performance; one researcher monitored the Resusci Anne Skill Reporter manikin, and one rescuer recorded the time, number of compressions and the 10-second breaks. A visual analog scale (VAS) was scored immediately after the completion of each CPR session.⁴²

Through statistical analysis of the collected data, changes in the quality of chest compressions and fatigue were assessed. All three scenarios declined in mean chest compression depth over time. The 100/10 method showed the deepest chest compressions followed by 200/10 and finally the CCC method. A percentage of adequate chest compressions per minute was computed using the chest compressions with adequate depth and the total number of chest compressions performed. The 100/10 method displayed the highest percentage of adequate chest compressions, then 200/10 and CCC followed. There was no statistical difference between chest

compression rate or incomplete chest recoil between all three groups. The data correlating with these findings are displayed in Table 7.⁴²

Table 7. Compression rate, depth, and total number of compressions after 10 minutes of CCC

Components of CPR	CCC method	200/10 method	100/10 method	p-value
Total number of chest compressions	1151.9 ± 128.2	1074.1 ± 114.2	996.0 ± 87.8	< 0.001
Number of compressions at proper depth	467.9 ± 444.2	589.8 ± 437.5	596.1 ± 388.5	0.183
Compression rate (compressions per minute)	119.0 ± 14.1	116.6 ± 20.5	119.3 ± 13.5	0.606
Ratio of adequate chest compressions per minute	0.3	0.49	0.51	< 0.05
Compression depth (cm)	45.24	48.69	50.4	< 0.05

Fatigue was the highest for the CCC method compared to the 100/10 method ($p= 0.045$). A 10-second rest period decreased the level of fatigue and increased the effectiveness of chest compressions performed.⁴² In conclusion, adding a break between compressions or changing rescuers increased adequate chest compressions and decreased fatigue.

2.3.5. Body Composition of the Rescuer

Body composition of the rescuer is a factor for the effectiveness of CPR and the decreased fatigue level of the rescuer. Eighteen participants ($m= 10$, $f= 8$) were separated into a light or heavy group according to the Japanese average weight based on each sex. The researchers of the study compared a light group of nurses to a heavy group using surface EMG to determine if weight affected the quality of chest compressions. The light group of nurses, compared to the heavy group, activated the trapezius ($p< 0.01$), rectus abdominus ($p< 0.05$),

external obliques ($p < 0.01$), and rectus femoris muscles ($p < 0.05$) to produce the force needed to perform chest compressions. The force then transferred to the erector spinae once decompression was performed. No decrease was found in adequate depth for the heavy group, but the adequate depth decreased over time for the light group ($p = 0.028$). RPE scores were recorded every minute during all five minutes of CPR. Using a Mann-Whitney U test, there was a statistically significant difference between the two groups and the reported RPE scores ($p < 0.05$). Wilcoxon sign rank tests were used to determine a statistically significant difference between each minute the RPE scores were recorded for each group (light group- $P < 0.05$, heavy group- $p < 0.05$). Decreased body weight requires an increase in muscles activated to perform chest compressions compared to increased body weight. It is proposed that if a rescuer is lower than the average weight according to his or her sex, he or she will experience fatigue at a faster rate than a rescuer who is above the average weight.¹⁶

EMT level, BMI, and fitness level were evaluated to investigate the relationship with quality chest compressions administered. A study with 95 EMTs who had rankings of EMT-1, which is EMT basic in the United States and has 40 hours of education; EMT-2, which is EMT intermediate in the U.S. and has 280 hours of education; and EMT-paramedic, which is EMT-P in the US and has 1,280 hours of education. Each participant took a pre-test consisting of two minutes of compression-only CPR. Each participant's sex, age, height, weight, body mass index, arm length, leg length, and exercise habits were obtained before performing the study. It was also recorded if the participant had taken a CPR course within the last three months leading up to the study. CPR was performed at 100 compressions per minute at a depth of five centimeters, and each participant was assigned to a group according to his or her performance during the pre-test.⁴³

Statistical analysis was computed to determine the relationship of body composition, fitness level, and the effectiveness of CPR. A logistic regression analysis was conducted and resulted in the total exercise time per week associated with high-quality CPR being performed by the participant (odds ratio= 0.004, $p= 0.044$). Lin et al. developed an index to predict high-quality CPR in a rescuer. This index is BMI x ExeTime, where BMI is the body mass index and ExeTime is the exercise time of the rescuer. This was computed using the area under the receiver operating curve of 0.718 (95% confident interval= 0.613-0.824, $p< 0.001$) and a cut off value of 4,316.7 kg·min.m² (sensitivity= 0.722, specificity= 0.678). The BMI of a rescuer and the exercise per week significantly increases the effectiveness of CPR which will increase the survivability of the patient suffering from cardiac arrest.⁴³

2.3.6. Overall Strength of the Rescuer

Torque, force production, and grip strength can also be indicators of quality CPR. These variables were assessed using 20 healthy females who were certified in basic life support performed two sessions of CPR for 10 minutes. The participants were included in the study if they did not have prior or existing neuromuscular, musculoskeletal, or cardiopulmonary conditions and had a BMI between 19 and 35 kilograms per meter squared (kg/m²). A Resusci Anne CPR Skillreporter was used for the administration of CPR and recorded the depth and rate of the chest compressions and a force plate was placed underneath the manikin to measure the force of the chest compressions. Fatigue was determined with the force of the chest compressions, ratings of perceived exertion (RPE), and blood lactate levels. Surface electromyography was used to assess eleven different muscles, i.e. the triceps brachii, anterior deltoid, pectoralis major, biceps brachii, latissimus dorsi, upper trapezius, middle trapezius, erector spinae, external oblique, hamstring, and quadriceps. Reflective markers were applied to

the participants to assess the biomechanics of the joints. Continuous chest compressions and 30:2 were the two CPR sessions the participants performed. Half of the participants were randomized to perform 30:2 CPR and the other half were randomized to perform continuous chest compressions. The participants performed CPR until their RPE, which was reported at five minutes and at the end of the CPR session, was 17, or they were told to stop. The compression rate, compression depth, video analysis and force were recorded continuously through the 10 minutes. A second session of CPR was performed with the other type of CPR, 30:2 or continuous chest compressions, that was not completed in the first session and the procedure was repeated.⁴⁴

Two separate three-way mixed factorial analyses were conducted to compare the two sessions. Three subjects were unable to perform the full ten minutes of the continuous chest compressions. Table 8 displays the comparison of components between both types of CPR after performing CPR for ten minutes.⁴⁴

Table 8. Comparison of the components of 30:2 CPR and continuous chest compressions after performing for 10 minutes

Components of CPR	30:2 CPR	Continuous chest compressions	p-value	F	η^2
Average compression rate (compressions per minute)	98.9 ± 5.7	92 ± 3.5	< 0.001	(1,17) = 16.6	0.97
Average compression depth (mm)	40.3 ± 2.5	36.3 ± 3.0	< 0.004	(1,16) = 11.4	0.89
Percentage of compressions at a depth of at least 38 mm (%)	62.8 ± 16.4	46.6 ± 16.8	0.05	(1,16) = 4.5	0.52
Compression forces (N)	427.5 ± 5.9	391.1 ± 5.7	0.02	(1,14) = 7.12	0.70
Rate of perceived exertion	14.5 ± 0.2	15.5 ± 0.2	< 0.001	(1,18) = 19.12	0.99
Blood lactate levels (mM/L)	2.5 ± 0.5	3.0 ± 0.1			

Providing quality chest compressions requires the body to produce enough force to compress the chest to the proper depth and at the proper rate. The force production needed for quality chest compressions is achieved through gravity and torque from hip flexion, but when rescuers become fatigued, the torque begins to come from hip extension (F(1,14)= 39.88, p< 0.001, $\eta^2= 0.999$). This change in torque results in decreased force and torque in the arms. Due to the decrease in force and torque down the arms, there was a decrease in rigidity of shoulder flexion and elbow extension at the end of CPR compared to the beginning. These factors all contributed to the decrease in chest compression depth and compression force needed for adequate and effective chest compressions.⁴⁴ The proper force production and torque are needed

to perform adequate chest compressions at the proper depth and rate, but when the rescuer becomes fatigued, the force and torque decrease which decreases the effectiveness of CPR.

Muscle strength of the rescuer can also determine the overall strength of the rescuer and in turn affect the performance of CPR. The number of adequate chest compressions was compared to the rescuers' BMI and muscle strength. Demographics of 63 participants (m= 19, f= 44) were recorded including height; weight; BMI; strength, which was assessed through a hand dynamometer; and cardiorespiratory health with a maximal voluntary cardiopulmonary exercise test. Cardiopulmonary fitness was measured with a maximum effort test using the Bruce Protocol on a treadmill ergometer while a treadmill stress electrocardiogram was placed on the subject. During the study, participants were to perform CPR for 20 minutes or until exhausted. Adequate compressions consisted of a rate of 100-120 compressions per minute, 100% of the compressions in the center of the chest, full chest recoil, compression depth of 50-60 mm, and equal amounts of compression and relaxation times. The total effect produced by muscle strength was 55% ($z= 2.396$, $p= 0.008$). BMI and muscle strength were positively associated with a p-value of less than or equal to 0.001, and BMI was positively associated with more adequate chest compressions ($p\leq 0.001$). When BMI and muscle strength were combined, they were also positively associated with adequate chest compressions ($p\leq 0.05$ and $p\leq 0.001$, respectively).⁴⁵ Lopez-Gonzalez et al.⁴⁵ found hand grip strength is correlated to effectiveness and quality of chest compressions. In conclusion, muscle strength increases a rescuer's amount of adequate compressions and increases the amount of time a rescuer is able to perform CPR.

2.4. Conclusion

Modifications and changes continue to be made to CPR through conclusions made by researchers whose goal is to identify the best CPR practices to increase survivability. Some

modifications have been the compression depth from 1.5 inches to two inches, compression rate from 100 bpm to 120 bpm, and allowing the chest to fully recoil. The biggest changes have been made to the ratio of chest compressions. In 2000, CPR increased from five chest compressions and one rescue breath to 15 chest compressions and two breaths. In 2005, the ratio increased again to 30 chest compressions and two breaths. Continuous chest compressions is the latest significant revision to CPR and was first introduced in 2010.

Continuous chest compressions are the latest update to the AHA CPR Guidelines and are emphasized for lay rescuers to perform during a cardiac arrest event. Continuous chest compressions remove rescue breaths, which the AHA discovered were being performed inaccurately by lay rescuers. Despite the benefits of continuous chest compressions and the easy execution, they potentially increase the fatigue experienced by rescuers. Fatigue may be decreased through different characteristics of the rescuer such as gender, BMI, and strength. Fatigue can also be decreased by changing rescuers when fatigue starts to set in or adding breaks in between the chest compressions. Decreasing fatigue in rescuers may increase the effectiveness of chest compressions which in turn will increase the survivability of cardiac arrest events.

3. METHODOLOGY

3.1. Purpose of the Study

The purpose of this research study was to analyze effectiveness of chest compressions during two different protocols: 30 compressions: 10-second break (30:10) and as many compressions as possible with a 10-second break (CC:10) when the participant chose to take the break(s). The secondary purpose was to evaluate rescuer fatigue through subjective reporting and objective measures of musculoskeletal strength measured with hand grip dynamometer.

The research design utilized two protocols (30 and continuous) as the primary independent variables. Gender, BMI, and hand grip strength were dependent variables for research questions one and two. Finally, to analyze fatigue, the independent variables were the two separate protocols, and the dependent variables were the Ratings of Perceived Exertion (RPE).

Q₁-What is the relationship among participant traits (BMI and average hand grip strength) and performance on dependent variables (depth %, depth mm, and chest recoil)?

Q₂-What is the relationship between participant traits (BMI and average hand grip strength) and self-reported fatigue at the nine-minute time point for the 30:10 and continuous compressions protocols?

Q₃-What is the difference between reported fatigue levels at three, six, and nine minutes of CPR performance when comparing 30:10 and continuous compressions protocols?

3.2. Participants

Eighteen (f= 9, m= 9) individuals (21.94 ± 3.67 years) were recruited by a convenience sample of the local university and surrounding communities via e-mail listserv and word-of-mouth. Participants were currently certified in CPR as a lay rescuer (AHA: Heartsaver;

American Red Cross: Adult CPR/AED), and individuals were not currently employed as an allied healthcare professional (EMR, EMT, CNA, etc.). Exclusion criteria included any musculoskeletal injuries to the upper extremity and back as well as cardiac issues that would decrease the participant's ability to perform high-quality CPR safely and effectively.

3.3. Documentation

Prior to data collection, the study was approved through the Institutional Review Board at North Dakota State University. Informed consent forms were read and signed by each participant. Data collection was conducted in the Athletic Training and Exercise Science Laboratory at North Dakota State University.

3.4. CPR Performance

Four protocols were originally proposed to include a compression to a 10-second break ratio of: 30:10; 50:10²³; 100:10⁴²; and finally, as many compressions as possible with a 10-second break (CC:10) when the participant chooses to take the break(s). These data for the 50:10 and 100:10 CPR protocols were not analyzed due to inaccuracy during the data collection of the CPR protocols. Only data from the 30:10 and continuous chest compressions protocol with 10-second breaks (CC:10) were used for analysis. Each protocol was performed for 8 minutes and 59 seconds, which is the national average of an ambulance to arrive at an emergency in an urban environment.^{38,39} The original methodology proposed that two protocols would be performed in one day with a 15-minute break taken between each protocol. The first day of data collection was going to span approximately 35-45 minutes, and the second day was going to take 20-25 minutes. Participants were originally scheduled for a two-day session with at least 24 hours and no more than 72 hours between the two.

On Day 1 of data collection, participants read and signed an informed consent form approved by the IRB. Demographics of each participant were recorded, which included: gender, age, CPR status, height, weight, and subsequent BMI were calculated. Hand grip strength was assessed and recorded using a hand grip dynamometer. Hand grip strength was tested three times and the average was taken of those three tests. Each participant was fitted with a mask for the metabolic cart (Parvomedics) as well as attached with the gas exchange adapter and hose. Following demographics, each participant was randomized into the four separate protocols. The original methodology included two protocols performed during day one of data collection, which included a smaller ratio (30:10, 50:10²³) and a larger ratio (100:10⁴², 1 10-second break protocol). Day 2 originally consisted of the remaining protocols the individual had not yet performed. The protocols were randomized by the researchers and were not made known to the participants until the test was initiated. Metabolic VO₂ consumption and heart rate were measured through the metabolic cart (Parvomedics) and were recorded every 15 seconds. Due to inaccuracy with the Parvo data during the CPR protocols, these data were not able to be used for analysis.

The guidelines for CPR were reviewed with each participant including full chest recoil, 1.5 to 2-inch depth, 100-120 compressions per minute, and proper hand placement. After the review, the participants had one minute of practice with deliberate feedback from the Resusci Anne® QCPR Manikin Resusci Anne® QCPR Manikin (Laerdal Medical AS, Stavanger, Norway). All chest compressions were performed on a Resusci Anne® QCPR Manikin Resusci Anne® QCPR Manikin (Laerdal Medical AS, Stavanger, Norway), which is medium-fidelity equipment that can record components of CPR such as: rate of compressions, depth of compressions, chest recoil, hand placement, etc.

Each session consisted of 8 minutes and 59 seconds during which participants were asked to indicate fatigue by pointing to or saying a number according to the Borg Scale. For this study, fatigue was defined as the rescuer self-determining when he or she feels severe tiredness due to CPR performance. Rate of perceived exertion (RPE) and VO₂ consumption were measured every three minutes throughout the CPR session. Despite VO₂ consumption being recorded, these data were not used for analysis. If a participant reached maximum fatigue and was unable to finish 8 minutes and 59 seconds of CPR, this was recorded but was considered a “successful” trial. There were no participants who were unable to complete all the sessions of CPR.

3.5. Statistical Analysis

Statistical analysis for the approved research was computed using SPSS software Version 24.0 (Armonk, NY). Data were analyzed using descriptive statistics and multiple linear regressions. Post hoc t-tests were completed when statistically significant results were found.

3.6. Conclusion

The purpose of this study was to determine the effectiveness of continuous chest compressions compared across two different protocols: 30 compressions with a 10-second break (30:10) and as many compressions as possible with a 10-second break (CC:10). The secondary purpose was to evaluate rescuer fatigue through participant-reported fatigue scale. As lay rescuers have been asked to provide CPR for cardiac arrest victims, the results of this research can be added to the existing evidence-based recommendations for future consideration of CPR protocols as determined by the AHA. Continuous chest compressions have been suggested for lay rescuers, but continuous chest compressions potentially creates fatigue. The results of this study will also help identify which protocol had the least amount of fatigue reported by the rescuer.

4. RESULTS

4.1. Demographics

The initial goal of this study was to recruit 24 (m= 12, f= 12) participants to measure subjective and objective fatigue levels during four different CPR protocols. Due to concerns of inaccuracy with the objective fatigue data collection, data from 18 (m= 9, f= 9) participants have been analyzed with the updated research questions. The demographic data of age, years certified, height, weight and BMI for the 18 participants is shown in Table 9. Hand grip strength was measured using a hand grip dynamometer and each participant was tested three times. The data from the hand grip strength measurements including the average of all three tests is provided in table 10.

Table 9. Participant demographics (mean, standard deviation, minimum, and maximum)

	n	Age (years)	Years Certified	Height (m)	Weight (kg)	BMI (kg/m ²)
Male	9	22.44 ± 4.13	3.67 ± 1.87	1.78 ± 0.06	76.61 ± 12.15	24.06 ± 2.85
		Min: 19	Min: 1	Min: 1.71	Min: 55.6	Min: 18.62
		Max: 32	Max: 6	Max: 1.87	Max: 96.64	Max: 28.24
Female	9	21.44 ± 3.32	3.16 ± 2.06	1.67 ± 0.03	69.78 ± 13.88	24.7 ± 4.51
		Min: 18	Min: 0.08	Min: 1.61	Min: 57.13	Min: 21.01
		Max: 29	Max: 6	Max: 1.71	Max: 98.34	Max: 34.93
Total	18	21.94 ± 3.67	3.41 ± 1.93	1.73 ± 0.07	73.20 ± 12.14	24.52 ± 3.69
		Min: 18	Min: 0.08	Min: 1.61	Min: 55.6	Min: 18.62
		Max: 32	Max: 6	Max: 1.87	Max: 98.34	Max: 34.93

Table 10. Hand grip strength (measured in kilograms)

	Grip Test 1	Grip Test 2	Grip Test 3	Grip Average
Male	53.89 ± 10.40	51.56 ± 11.45	51.11 ± 11.53	52.19 ± 10.99
	Min: 40	Min: 32	Min: 30	Min: 34
	Max: 70	Max: 68	Max: 67	Max: 68.33
Female	36.56 ± 7.16	34.11 ± 8.52	33.89 ± 9.36	34.85 ± 8.52
	Min: 27	Min: 23	Min: 18	Min: 22.67
	Max: 50	Max: 51	Max: 52	Max: 51
Total	45.22 ± 12.43	42.83 ± 13.28	42.5 ± 13.50	43.52 ± 12.97
	Min: 27	Min: 23	Min: 18	Min: 22.67
	Max: 70	Max: 68	Max: 67	Max: 68.33

4.2. CPR Quality Compared to BMI and Hand Grip Strength

CPR quality data were collected for all 18 participants for both the 30:10 session and the continuous chest compressions session. The 2015 AHA CPR Guidelines recommends rescuers are to depress the chest a minimum of 2 inches but not exceed 2.4 inches. The chest compression rate should be 100-120/min and the rescuer should allow the chest to fully recoil. Data for the 30:10 session is displayed in Table 11 and the data for the continuous chest compressions session is displayed in Table 12.

Table 11. CPR quality for 30:10 session

	Depth (%)	Depth (mm)	Recoil (%)
Male	85.78 ± 26.54	55.11 ± 4.78	89.67 ± 20.85
	Min: 22	Min: 45	Min: 35
	Max: 100	Max: 61	Max: 100
Female	58.33 ± 28.78	50.22 ± 5.78	96.44 ± 4.77
	Min: 1	Min: 38	Min: 88
	Max: 100	Max: 60	Max: 100
Total	72.06 ± 30.34	52.67 ± 5.73	93.06 ± 15.08
	Min: 1	Min: 38	Min: 35
	Max: 100	Max: 61	Max: 100

Table 12. CPR quality for continuous compression session

	Depth (%)	Depth (mm)	Recoil (%)
Male	37.56 ± 46.60	45 ± 8.19	55.33 ± 31.63
	Min: 0	Min: 35	Min: 14
	Max: 100	Max: 57	Max: 99
Female	32.44 ± 33.14	45.67 ± 6.73	86.56 ± 18.08
	Min: 0	Min: 34	Min: 47
	Max: 96	Max: 57	Max: 100
Total	35 ± 39.31	45.33 ± 7.28	70.94 ± 29.71
	Min: 0	Min: 34	Min: 14
	Max: 100	Max: 57	Max: 100

The first research question explored the relationship between participant demographics (BMI, average hand grip strength, and gender) and performance on CPR as measured by the percentage of compressions at the appropriate depth, the average depth of compressions measured in millimeters, and percentage of compressions with full chest recoil. Thus, the dependent variables were depth percentage, millimeter depth, and chest recoil while the independent variables were the participants' traits. Separate linear regression models were used to explore the relationship between the independent variables and each of the dependent variables.

BMI was the first independent variable used to compare to the dependent variables. The first portion of research question one relates to the 30:10 CPR protocol. None of the analyses for the dependent variables in the 30:10 CPR protocol were statistically significant. The regression for depth percentage was not significant ($p= 0.198$) with R^2 as 0.101. The regression for depth millimeters was also not significant with a p -value of 0.220 and R^2 as 0.092. Finally, the regression for chest recoil was not significant ($p= 0.606$) with R^2 as 0.017. The second portion of research question one relates to the continuous chest compressions protocol. None of the

analyses for the dependent variables in the continuous chest compressions protocol were statistically significant. The regressions for depth percentage ($p= 0.897$, $R^2= 0.001$), millimeter depth ($p= 0.768$, $R^2= 0.006$), and chest recoil ($p= 0.281$, $R^2= 0.072$) were not significant.

Hand grip strength for each participant was averaged after a total of three trials were obtained. For the 30:10 CPR protocol, statistical significance was noted for depth percentage and depth millimeters. The regression for depth percentage ($p= 0.013$, $R^2= 0.327$) and millimeter depth ($p= 0.037$, $R^2= 0.245$) were statistically significant. No statistical significance was found for chest recoil, which had a p-value of 0.170 with R^2 as 0.114. None of the analyses for the dependent variables in the continuous chest compressions protocol were statistically significant. The regression for depth percentage ($p= 0.713$, $R^2= 0.009$), millimeter depth ($p= 0.393$, $R^2= 0.046$), and chest recoil ($p= 0.482$, $R^2= 0.031$) were not significant.

4.3. Subjective Fatigue Levels

The Rate of Perceived Exertion (RPE) was assessed through the Borg scale, which was comprised of numbers from 6 to 20 with 6 being no exertion and 20 being maximum exertion.⁴⁶ Each participant was asked to report the subjective fatigue levels experienced during each CPR session at 0, 3, 6, and 9 minutes. The participants would point or say a number on a Borg scale for RPE. The data collected from the RPE scores are shown in Figure 1 for both CPR sessions. During the continuous chest compression session, the participants were allowed to take as many 10-second breaks as needed but were instructed to perform CPR for as long as they could before taking a break. Data from the number of breaks taken is displayed in Figure 2.

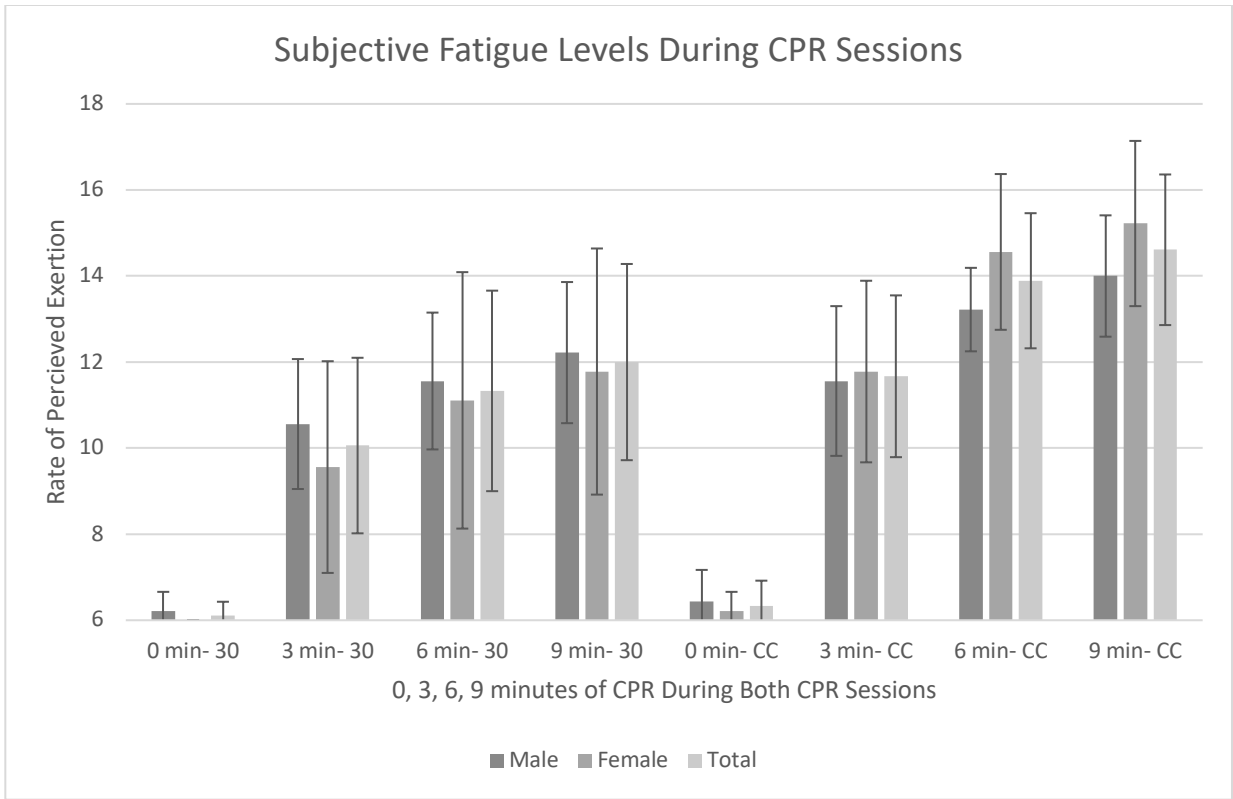


Figure 1. Subjective fatigue levels during CPR sessions

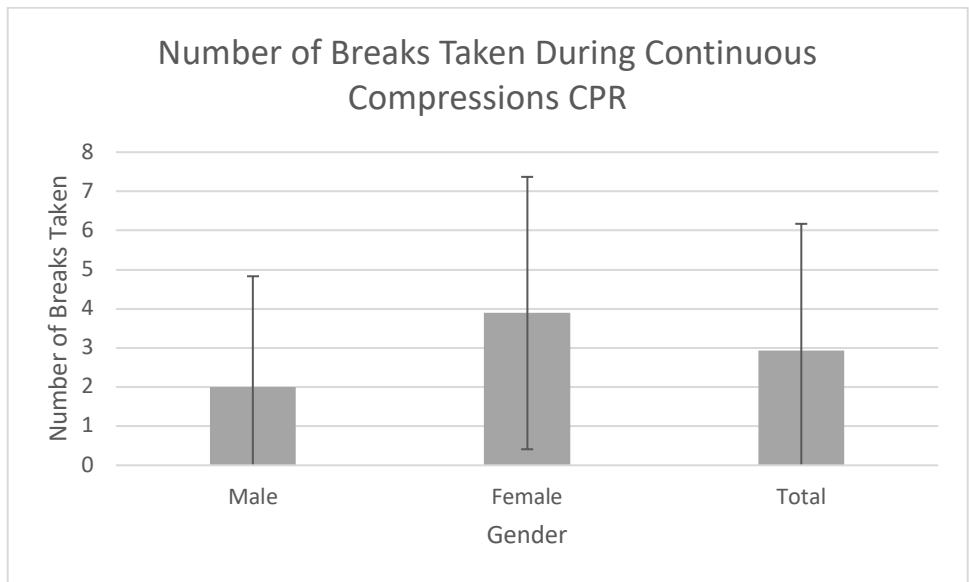


Figure 2. Number of breaks taken during continuous compressions CPR

The second research question explored the relationship between participant characteristics (BMI and hand grip strength) and self-reported fatigue for both CPR sessions. To determine the relationship between participant demographics and fatigue, we calculated only the final report at the nine-minute interval. For the 30:10 CPR protocol, BMI was not statistically significant ($p= 0.598$) with R^2 as 0.018. For the continuous chest compressions protocol, BMI was also not statistically significant with a p -value of 0.814 and R^2 as 0.004. For the 30:10 CPR protocol, hand grip strength did not have a statistically significant relationship with self-reported fatigue ($p= 0.170$) with R^2 as 0.114. Interestingly, there was a statistically significant relationship for the continuous chest compression protocol between hand grip strength and fatigue ($p= 0.004$) with R^2 as 0.414.

Based on the results from the separate linear regressions, follow-up t -tests comparing gender to the three statistically significant variables were analyzed. Gender did not reveal statistically significant results for 30:10 CPR protocol depth percentage ($p= 0.782$), 30:10 CPR protocol millimeter depth ($p= 0.957$), or continuous chest compressions protocol RPE ($p= 0.344$).

The third research question explored the difference between the two protocols for self-reported fatigue levels at the three, six, and nine-minute time intervals. Each of the three comparisons yielded statistically significant results. At all three points, participants reported greater fatigue in the continuous chest compressions protocol compared to the 30:10 CPR protocol. Table 13 displays the RPE scores for each protocol and compares the RPE scores between the protocols.

Table 13. Comparing RPE scores for both compression-only CPR protocols

	3 minutes*		6 minutes**		9 minutes**	
	30:10	CC:10	30:10	CC:10	30:10	CC:10
RPE scores	10.056 ± 2.043	11.667 ± 1.879	11.333 ± 2.326	13.889 ± 1.568	12.000 ± 2.275	14.611 ± 1.754

*p= 0.005; **p= 0.000

In conclusion, a statistically significant relationship was determined between hand grip strength to depth percentage and millimeter depth ($p= 0.013$, $R^2= 0.327$; $p= 0.037$, $R^2= 0.245$) for the 30:10 protocol. A statistically significant relationship was found between the continuous chest compressions protocol with hand grip strength and fatigue levels ($p= 0.004$, $R^2= 0.414$) but was not found in the 30:10 CPR protocol. The continuous chest compressions protocol displayed greater reported fatigue at three, six, and nine minutes than the 30:10 protocol ($p= 0.005$, 0.000 , 0.000 , respectively).

5. DISCUSSION

The purpose of this research study was to analyze effectiveness of chest compressions during two different protocols: 30 compressions:10-second break (30:10) and as many compressions as possible with a 10-second break (CC:10) when the participant chose to take the break(s). The secondary purpose was to evaluate rescuer fatigue through subjective reporting and objective measures of musculoskeletal strength measured with hand grip dynamometer. Due to proposed changes by the AHA of lay rescuers performing continuous chest compressions, it is important to analyze rescuer demographics and self-reported fatigue as they relate to CPR performance. Previous researchers have reported the relationship of BMI and hand grip strength to CPR performance. However, a gap in research exists assessing fatigue levels and physiological characteristics of the rescuer with continuous chest compressions CPR and 30 compressions to a 10-second break.

5.1. Quality of CPR Performance Between Protocols

As the duration of CPR performance increases, the effectiveness of chest compressions decreases, which occurs at different times based on the characteristics of the rescuer. Previous research has demonstrated conflicting results pertaining to a decline in effectiveness of CPR performance. Ock et al.³⁴ concluded correct chest compressions decreased from one minute to the next throughout five minutes of CPR. Correct compressions were defined as the proper depth of four to five centimeters. Throughout the study, the participants were able to maintain adequate rates of around 110 compressions per minute. In contrast, Riera et al.³⁷ did not find diminished quality of continuous chest compressions, but they only compared the mean number of compressions performed per minute. Proper depth or full chest recoil was not assessed in the study. The researchers stopped the participants if the rates dropped below 25% of the guidelines

and the two minutes were restarted after the rescuer rested. The guidelines consisted of uninterrupted compressions at a rate of 100 compressions per minute. Two independent observers evaluated the sternal depression and hand placement during the session. The restart for the participants and the small duration of CPR performance could account for the lack of diminished quality of CPR, and ultimately, the conflicting results.³⁷ The current study did not directly analyze each minute of CPR quality but did analyze the total CPR quality of both protocols. All three categories of CPR quality were diminished during the continuous chest compressions protocol. The proper depth was only achieved $35 \pm 39.31\%$ of the time and the average depth for all participants was 45.33 ± 7.28 mm. The proper depth of chest compressions should be 50-60 mm, which was not achieved throughout the continuous chest compressions protocol in the current study. Chest recoil was maintained $70.94 \pm 29.71\%$ of the continuous chest compression CPR session for both genders, which was diminished compared to the $93.06 \pm 15.08\%$ maintained during the 30:10 CPR session. Previous research concluded conflicting results regarding diminished effectiveness of CPR, but the current research displayed diminished quality of CPR during the continuous chest compressions protocol compared to the AHA CPR Guidelines.

In addition to comparing the effectiveness of CPR throughout the duration of performance, previous research has also compared the quality of CPR across different protocols. Shin et al.⁴⁰ concluded a decreased number of adequate compressions with depth of more than 5 cm at the end of the continuous CPR compared to the standard CPR. Males had an increased number of adequate compressions and a more accurate rate than the females. Despite the increase in the quality of CPR in the male participants, the researchers concluded a significant decrease in the overall effectiveness of chest compressions during the continuous CPR than the

standard CPR. Similar to these results, Min et al.⁴² compared the effectiveness of CPR across three different continuous chest compressions protocols. The continuous chest compressions protocols consisted of 100 compressions with a 10-second break (100/10), 200 compressions with a 10-second break (200/10) and continuous chest compressions (CC) with no break for 10 minutes. The 100/10 protocol recorded the highest percentage of adequate chest compressions with the most compressions at the proper depth. The CC protocol recorded the highest number of chest compressions, but the compressions were not at an adequate depth.⁴² In addition to the findings of previous research, the current research concluded a significant decrease in all three categories of CPR (depth percentage, depth in millimeters, and chest recoil) during the continuous chest compressions protocol. During the 30:10 protocol, males were able to achieve the adequate depth almost 86% of the total time and females were only able to achieve adequate depth 58% of the time. Females performed better chest recoil than males during both protocols. During the continuous chest compression protocol, neither gender was able to perform chest compressions with the proper depth of 50-60 mm. Chest recoil was also diminished during the continuous chest compression protocol. When continuous chest compressions are performed, the effectiveness of chest compressions decreases, no matter the gender.

5.2. Comparing BMI and Hand Grip Strength to CPR Performance

Previous research has demonstrated that a higher BMI is correlated with improved CPR performance. Lopez-Gonzalez et al.⁴⁵ concluded the effectiveness of chest compressions was improved with both BMI and muscle strength as well. The results of the current study contradict what was found from the study by Lopez-Gonzalez et al.⁴⁵ The current study showed no relationship between BMI and the performance in either CPR session. Lopez-Gonzalez et al.⁴⁵ had each participant perform 20 minutes of CPR or until exhaustion whereas the current study's

participants performed CPR for eight minutes and 59 seconds. Even though Lopez-Gonzalez et al.⁴⁵ computed higher BMIs equated to higher CPR performance, other researchers⁴³ as well as the current researchers disagree with those findings.

Similar to the results of the current study, Lin et al.⁴³ did not attribute BMI to higher quality CPR performance. The researchers were, however, able to develop an index that predicted high-quality CPR. The index was comprised of BMI multiplied by the average total exercise time of the rescuer.⁴³ Despite recording the exercise time for each rescuer for the present study, it was not a part of the research questions and, therefore, was not analyzed. The participants indicated self-reported exercise time throughout the week for cardiopulmonary health and weight lifting but it did not appear the data being reported was accurate. A future study analyzing fitness levels and exercise time via an accelerometer should be conducted. Previous research has debated the existence of a relationship between BMI and CPR performance, but the present study did not determine a relationship existed.

In addition to BMI, Lopez-Gonzalez et al.⁴⁵ measured hand grip strength and compared it to CPR performance. The hand dynamometer was used to establish the participants' muscle strength. The researchers determined a higher hand grip strength correlated with increased effective and quality chest compressions.⁴⁵ Similar to the results of the study by Lopez-Gonzalez et al.⁴⁵, Kim et al.⁴¹ computed a similar relationship between hand grip strength and both mean compression depth in millimeters and mean adequate compressions ratio in percentage. However, the researchers had participants perform CPR for four cycles of one-minute CPR with a minute rest or two cycles of two minutes of CPR with a two minute rest.⁴¹ Further, hand grip strength was used to describe the participants' overall muscle strength in a study conducted by Ock et al.³⁴ The researchers determined increased muscle strength correlated with an increase in

proper depth and rate of chest compressions.³⁴ The current study determined a relationship with hand grip strength and proper compression depth in millimeters and percentage during the 30:10 CPR protocol. However, there was no relationship with hand grip strength and proper depth for the continuous chest compressions CPR protocol. This could be due to the increase in fatigue levels experienced by the rescuer. Despite similarities in results, the studies had varying durations of time for CPR performance, including 20 minutes, four cycles of one-minute CPR with one minute of rest or two cycles of two-minute CPR with two minutes of rest, five minutes, or the current study of eight minutes and 59 seconds.^{34,41,45} Similar results were concluded in the current study with previous research about hand grip strength correlating with increased chest compression depth while performing 30:10 CPR protocol, mimicking the breaks in 30:2 CPR, but did not agree with the continuous chest compression protocol. Previous research and the current study have debated the existence of a relationship between BMI and the quality of CPR performed, but previous research has demonstrated a relationship between hand grip strength and quality CPR despite conflicting results in the current study.

5.3. Comparing BMI and Grip Strength with Self-Reported Fatigue

Physical characteristics of the rescuer, such as lower BMI and grip strength, may contribute to the amount of fatigue experienced by the rescuer. BMI has been determined to have a relationship with self-reported fatigue levels in rescuers. Hasegawa et al.¹⁶ determined there was a relationship between BMI and the RPE scores reported throughout CPR performance, which contradicts the results of the current study. No relationship was determined between BMI and RPE scores in the current study.¹⁶ The calculations only took place at the nine-minute interval instead of throughout the entire eight minutes and 59 seconds of the CPR performance due to the greatest RPE values occurring at the nine-minute mark. The conflicting results may be

due to the different time intervals CPR which were five minutes in Hasegawa et al.'s¹⁶ study and eight minutes and 59 seconds for the current study. Despite previous research determining a relationship between BMI and RPE levels, the present study did not find this same relationship.

Results related to the relationship between BMI and subjective fatigue levels are contradictory. Riera et al.³⁷ calculated no correlation was found between values of BMI and heart rate at one minute and two minutes. The mean VAS score reported were lower, meaning the participants felt little to no discomfort. A limitation to the study conducted by Riera et al.³⁷ was CPR was only performed for two minutes, which could be why there was no increase in fatigue levels.³⁷ The current study determined there was no relationship between BMI or hand grip strength and RPE scores for the 30:10 CPR protocol, or BMI and RPE scores for the continuous CPR protocol. Despite similar findings between Riera et al.³⁷ and the current study, Riera et al.³⁷ only performed CPR for two minutes, whereas the current study performed CPR for eight minutes and 59 seconds. There are conflicting findings in previous research about the effects BMI has on subjective fatigue experienced during CPR, but the present study did not determine a relationship between the two.

Instead of relying on subjective reporting, previous research has also measured fatigue through objective measures to understand the moment a rescuer experiences fatigue. Ock et al.³⁴ measured both subjective and objective fatigue through RPE scores and VO_2 . The researchers determined performing CPR is aerobic in nature because the volume of oxygen consumption and ratings of perceived exertion were in the aerobic phase of a maximal exercise test. The RPE levels, mean oxygen consumption and heart rate all increased throughout the performance of CPR. The researchers indicated performing CPR is a modest workload and requires 65% of the predicted maximum achievable workload. Ock et al.³⁴ did not directly analyze BMI or handgrip

strength with RPE scores or the VO_2 . Interestingly, the present study determined a relationship for the continuous chest compression protocol between hand grip strength and fatigue. There was no relationship between hand grip strength and fatigue experienced during the 30:10 CPR protocol, however. The varying differences between the two studies on hand grip strength and fatigue levels could be explained by the different time intervals for CPR performance. CPR was performed for five minutes during the study conducted by Ock et al.³⁴, but CPR was performed for eight minutes and 59 seconds in the current study. Despite contrasting findings for BMI and hand grip strength with fatigue levels, previous research has determined that subjective fatigue levels, as well as objective, increase throughout the duration of CPR performance.

5.4. Comparing Self-Reported Fatigue Levels Between Protocols

Previous research has determined an increase in fatigue occurs not only during CPR performance but also throughout different CPR protocols, which may lead to a protocol best fit for the rescuer and the patient. Min et al.⁴² recorded visual analog scores immediately after three CPR protocols, consisting of 100 chest compressions to a 10-second break (100:10), 200 chest compressions to a 10 second break (200:10), and continuous chest compressions without a break. Min et al.⁴² concluded continuous chest compressions increased fatigue levels more than the 100:10 CPR protocol. Similarly, the current study concluded the continuous chest compressions protocol displayed greater reported fatigue at three, six, and nine minutes than the 30:10 protocol. However, the current study was conducted using lay rescuers and Min et al.⁴² conducted data collection with emergency medical technicians. Another contrast in methodology between the study conducted by Min et al.⁴² and the current study was the time interval of CPR performance, which were 10 minutes for the Min et al.⁴² study and eight minutes and 59 seconds for the current study. Both Min et al.⁴² and the current study demonstrated that fatigue

experienced by the rescuer is a major concern when performing continuous chest compressions because it may affect the quality of chest compressions being delivered to the patient.

Objective fatigue has also been shown to effect the rescuer during continuous chest compressions in addition to subjective fatigue levels. Eight minutes of continuous chest compressions was performed using the depth and rates of both the AHA 2005 CPR Guidelines and the AHA 2010 AHA Guidelines in a study conducted by Yang et al.²⁷ The 2005 AHA Guidelines recommended the depth of chest compressions should be one and a half to two inches (1.5-2) for an adult and the 2010 AHA Guidelines recommend the chest should be depressed at least two inches. The rate of chest compressions was similar for both guidelines, but the 2005 AHA Guidelines simply stated 100 compressions per minute, whereas the 2010 AHA Guidelines stated the chest compression rate should be at least 100 compressions per minute. Fatigue levels were measured subjectively through RPE scores and objectively through heart rate and blood lactate levels. The researchers reported RPE scores during the 2010 AHA Guidelines group were higher along with increased heart rate and blood lactate levels when compared to the 2005 AHA Guidelines group.²⁷ Similarly, the current study also recorded an increase in fatigue levels with the continuous chest compressions protocol than the 30:10 CPR protocol. Despite similar results between the two studies, Yang et al.²⁷ did not have an upper limit to the compression rate, whereas the current study utilized the upper limit of 120 compressions as indicated in the 2015 AHA Guidelines. Objective fatigue levels along with subjectively-reported fatigue levels are increased throughout continuous chest compressions as reported by previous research and the current study.

Previous research has concluded rescuers experienced increased exertion during the continuous chest compressions CPR protocol when compared to other protocols with breaks or

ventilations. RPE scores, blood lactate levels, and force production were used to calculate the amount of fatigue experience by the participants during a “Hands-only”, or continuous chest compressions, protocol and a 30 compressions to two ventilations (30:2) protocol. Similar to the results of Yang et al.²⁷, Trowbridge et al.⁴⁴ determined an increase in RPE levels during the continuous chest compressions protocol compared to the 30:2. The difference between the results of the study conducted by Trowbridge et al.⁴⁴ and the current study is the amount of time chest compressions were administered as well as the 30:2 protocol. The present study performed the protocols for eight minutes and 59 seconds compared to the 10 minutes by Trowbridge et al.⁴⁴ The current study recruited participants from both genders and implemented a 30 compressions to a 10-second break, whereas Trowbridge et al.⁴⁴ recruited only female participants and utilized a 30:2 CPR protocol. All three of the studies outlined above relate to the results of the present study where fatigue, both objectively and subjectively, is greater when performing continuous chest compressions CPR, no matter the gender of the rescuer or experience level of the rescuer.

5.5. Limitations

The results of the present study may have been effected by limitations throughout the study. The first limitation was the number of participants who performed the CPR protocols. A larger sample size may have provided significant findings for the BMI or hand grip strength analysis. The second limitation was the inaccurate data collection while using the Parvo metabolic cart, which occurred during the CPR protocols. Having data from the Parvo metabolic cart would have allowed for analysis of objective fatigue and analysis of the other two CPR protocols that were not included in data analysis. Fatigue levels were only measured subjectively, which does not account for the metabolic changes in the body and does not give a true measure of fatigue. Analyses of the two original CPR protocols of 50:10 and 100:10 were

not conducted due to inaccurate data collection. The Resusci Anne® QCPR Manikin Resusci Anne® QCPR Manikin (Laerdal Medical AS, Stavanger, Norway) was a limitation because the participants were performing CPR in a simulated situation and not during a real cardiac arrest on a human patient. While taking an increased amount of breaks may decrease the amount of fatigue experienced by the rescuer, it decreases the effectiveness of the chest compressions because the amount of time chest compressions are not performed is increased and decreasing the patient's survivability. Although these limitations existed, the current study was able to find statistical significance and formulate some conclusions based on the results.

5.6. Future Research

The most effective continuous chest compression protocol has yet to be determined, but examining different protocols, including all four of the originally proposed protocols, will help distinguish the best protocol in decreasing rescuer fatigue and increasing survivability. Future research is necessary to make a definitive conclusion on the most effective approach to compression-only CPR. This study may be a resource for developing other methodologies for different compression-only CPR protocols, specifically focusing on reducing the fatigue of the rescuer both objectively and subjectively. The current study only addressed 30:10 and CC:10 protocols, but different protocols may increase the effectiveness of CPR without compromising the rescuers' fatigue levels.

Additionally, future studies are recommended to identify different physical fitness factors that may decrease rescuer fatigue. Analyzing the rescuers' daily activities through an accelerometer would allow for more objective data on fitness levels as well as possibly providing different physical activities being performed. The accelerometers would address inconsistencies in self-reporting fitness activities and the amount of physical activity time. Continuing to

research the best practices for compression only CPR will aid not only lay rescuers but also healthcare professionals.

5.7. Conclusions

This study adds to previous research focusing on continuous chest compressions. The present and previous studies have shown an increase in fatigue for rescuers who perform continuous chest compressions for a long period of time. Min et al.⁴² stated, “the issue of rescuer fatigue due to continuous chest compressions without rest during continuous chest compression-CPR has been raised, as it may decrease CPR quality (chest compression depth, rate, total number)”.⁴² Previous researchers along with the current researchers have concluded rescuers experience the most fatigue during continuous chest compressions, which decreases the effectiveness of compressions and, ultimately, the survivability of the patient. Future research is imperative for increasing the survivability of out-of-hospital cardiac arrest, and provide more resources to the AHA to formulate the CPR guidelines. Therefore, the current study contributes to the evidence-based medicine for CPR protocols.

REFERENCES

1. Sutton RM, French B, Meaney PA, et al. Physiologic monitoring of CPR quality during adult cardiac arrest: A propensity-matched cohort study. *Resuscitation*. 2016;106:76-82. doi:10.1016/j.resuscitation.2016.06.018.
2. Nehme Z, Andrew E, Nair R, Bernard S, Smith K. Recurrent out-of-hospital cardiac arrest. *Resuscitation*. 2017;121:158-165. doi:10.1016/j.resuscitation.2017.08.011.
3. Dainty RS, Gregory DE. Investigation of low back and shoulder demand during cardiopulmonary resuscitation. *Appl Ergon*. 2017;58:535-542. doi:10.1016/j.apergo.2016.04.013.
4. Ashton A, McCluskey A, Gwinnutt CL, Keenan AM. Effect of rescuer fatigue on performance of continuous external chest compressions over 3 min. *Resuscitation*. 2002;55(2):151-155. doi:10.1016/S0300-9572(02)00168-5.
5. Ochoa FJ, Ramalle-Gómara E, Lisa V, Saralegui I. The effect of rescuer fatigue on the quality of chest compressions. *Resuscitation*. 1998;37(3):149-152. doi:10.1016/S0300-9572(98)00057-4.
6. American Heart Association. About Cardiac Arrest. <https://www.heart.org/en/health-topics/cardiac-arrest/about-cardiac-arrest#.WwuL81MvzEY>. Published 2017. Updated March 31, 2017. Accessed March 15, 2018.
7. Wang J, Tang C, Zhang L, Gong Y, Yin C, Li Y. Compressing with dominant hand improves quality of manual chest compressions for rescuers who performed suboptimal CPR in manikins. *Am J Emerg Med*. 2015;33(7):931-936. doi:10.1016/j.ajem.2015.04.007.
8. American Heart Association. Web-based Integrated Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care - Part 5: Adult Basic Life Support and Cardiopulmonary Resuscitation Quality. ECCguidelines.heart.org.
9. Deakin CD, Nolan JP, Soar J, et al. European Resuscitation Council Guidelines for Resuscitation 2010 Section 4. Adult advanced life support. *Resuscitation*. 2010;81(10):1305-1352. doi:10.1016/j.resuscitation.2010.08.017.
10. Betz AE, Callaway CW, Hostler D, Rittenberger JC. Work of CPR during two different compression to ventilation ratios with real-time feedback. *Resuscitation*. 2008;79(2):278-282.
11. Berg RA, Hemphill R, Abella BS, et al. Part 5: Adult basic life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122(suppl. 3):S685-S705. doi:10.1161/CIRCULATIONAHA.110.970939.

12. American Heart Association. Part 4: Adult Basic Life Support. *Circulation*. 2005;112(24 suppl):IV-19 LP-IV-34. http://circ.ahajournals.org/content/112/24_suppl/IV-19.abstract.
13. Chugh SS, Reinier K, Teodorescu C, et al. Epidemiology of sudden cardiac death: Clinical and research implications. *Prog Cardiovasc Dis*. 2008;51(3):213-228. doi:10.1016/j.pcad.2008.06.003.
14. Iwami T, Kawamura T, Hiraide A, et al. Effectiveness of bystander-initiated cardiac-only resuscitation for patients with out-of-hospital cardiac arrest. *Circulation*. 2007;116(25):2900-2907. doi:10.1161/CIRCULATIONAHA.107.723411.
15. SOS-KANTO study group. Cardiopulmonary resuscitation by bystanders with chest compression only (SOS-KANTO): an observational study. *Lancet*. 2007;369(9565):920-926. doi:10.1016/S0140-6736(07)60451-6.
16. Hasegawa T, Daikoku R, Saito S, Saito Y. Relationship between weight of rescuer and quality of chest compression during cardiopulmonary resuscitation. *J Physiol Anthropol*. 2014;33:16-22. doi:10.1186/1880-6805-33-16.
17. Baskett PJ, Peter J. Safar, the early years 1924-1961, the birth of CPR. *Resuscitation*. 2001;50:17-22. doi:10.1016/S0300-9572(01)00391-4.
18. Hurt R. Modern cardiopulmonary resuscitation--not so new after all. *J R Soc Med*. 2005;98:327-331. doi:10.1258/jrsm.98.7.327.
19. Wik L, Steen PA. The ventilation/compression ratio influences the effectiveness of two rescuer advanced cardiac life support on a manikin. *Resuscitation*. 1996;31:113-119. doi:10.1016/0300-9572(95)00921-3.
20. American Heart Association. Part 3: Adult Basic Life Support. *Circulation*. 2000;102(suppl 1):I-22 - I-59. http://circ.ahajournals.org/content/102/suppl_1/I-22.abstract.
21. Christenson JM, Solimano AJ, Williams J, et al. The new American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiac care: presented by the Emergency Cardiac Care. *C Can*. 1993;149(5):585-590.
22. Eberle B, Dick WF, Schneider T, Wisser G, Doetsch S, Tzanova I. Checking the carotid pulse check: diagnostic accuracy of first responders in patients with and without a pulse. *Resuscitation*. 1996;33:107-116.
23. Bjørshol CA, Søreide E, Torsteinbø TH, Lexow K, Nilsen OB, Sunde K. Quality of chest compressions during 10 min of single-rescuer basic life support with different compression: ventilation ratios in a manikin model. *Resuscitation*. 2008;77:95-100. doi:10.1016/j.resuscitation.2007.11.009.

24. Odegaard S, Saether E, Steen PA, Wik L. Quality of lay person CPR performance with compression:ventilation ratios 15:2, 30:2 or continuous chest compressions without ventilations on manikins. *Resuscitation*. 2006;71:335-340. doi:10.1016/j.resuscitation.2006.05.012.
25. Yasuda Y, Kato Y, Sugimoto K, et al. Muscles used for chest compression under static and transportation conditions. *Prehosp Emerg Care*. 2013;17(2):162-169. doi:10.3109/10903127.2012.749964.
26. Jiang C, Jiang S, Zhao Y, Xu B, Zhou XL. Dominant hand position improves the quality of external chest compression: A manikin study based on 2010 CPR guidelines. *J Emerg Med*. 2015;48(4):436-444. doi:10.1016/j.jemermed.2014.12.034.
27. Yang Z, Li H, Yu T, et al. Quality of chest compressions during compression-only CPR: A comparative analysis following the 2005 and 2010 American Heart Association guidelines. *Am J Emerg Med*. 2014;32:50-54. doi:10.1016/j.ajem.2013.09.043.
28. Edelson DP, Abella BS, Kramer-johansen J, et al. Effects of compression depth and pre-shock pauses predict defibrillation failure during cardiac arrest. *Resuscitation*. 2006;71:137-145. doi:10.1016/j.resuscitation.2006.04.008.
29. Stiell IG, Brown SP, Nichol G, et al. What is the optimal chest compression depth during out-of-hospital cardiac arrest resuscitation of adult patients? *Circulation*. 2014;130:1962-1970. doi:10.1161/CIRCULATIONAHA.114.008671.
30. Hallstrom A, Ornato JP. Public-Access Defibrillation and Survival after Out-of-Hospital Cardiac Arrest. *N Engl J Med*. 2004;351(7):637-646. doi:10.1056/NEJMoa1611594.
31. Higdon TA, Heidenreich JW, Kern KB, et al. Single rescuer cardiopulmonary resuscitation: Can anyone perform to the guidelines 2000 recommendations? *Resuscitation*. 2006;71:34-39. doi:10.1016/j.resuscitation.2006.02.020.
32. Zhou XL, Li L, Jiang C, et al. Up-down hand position switch may delay the fatigue of non-dominant hand position rescuers and improve chest compression quality during cardiopulmonary resuscitation: A randomized crossover manikin study. *PLOS One*. 2015;10(8):1-11. doi:10.1371/journal.pone.0133483.
33. Shin DH, Cho JH, Park SO. Individualized rescuer change by a team leader during uninterrupted cardiopulmonary resuscitation. *Eur J Emerg Med*. 2016;23:263-268. doi:10.1097/MEJ.0000000000000261.
34. Ock S-M, Kim Y-M, Chung JH, Kim SH. Influence of physical fitness on the performance of 5-minute continuous chest compression. *Eur J Emerg Med*. 2011;18:251-256. doi:10.1097/MEJ.0b013e328345340f.
35. Bjørshol CA, Sunde K, Myklebust H, Assmus J, Søreide E. Decay in chest compression quality due to fatigue is rare during prolonged advanced life support in a manikin model. *Scand J Trauma Resusc Emerg Med*. 2011;19:46-52. doi:10.1186/1757-7241-19-46.

36. Rad M, Rad M. A study of the factors related to cardiopulmonary resuscitation physical fatigue & the quality of resuscitation. *Acta Fac Medicae Naissensis*. 2017;34(1):43-53. doi:10.1515/afimnai-2017-0006.
37. Riera SQ, González BS, Álvarez JT, Fernández M del MF, Saura JM. The physiological effect on rescuers of doing 2 min of uninterrupted chest compressions. *Resuscitation*. 2007;74:108-112. doi:10.1016/j.resuscitation.2006.10.031.
38. Pons PT, Markovchick VJ. Eight minutes or less: Does the ambulance response time guideline impact trauma patient outcome? *J Emerg Med*. 2002;23(1):43-48. doi:10.1016/S0736-4679(02)00460-2.
39. Pons PT, Haukoos JS, Bludworth W, Cribley T, Pons KA, Markovchick VJ. Paramedic response time: Does it affect patient survival? *Acad Emerg Med*. 2005;12(7):594-600. doi:10.1197/j.aem.2005.02.013.
40. Shin J, Hwang SY, Lee HJ, et al. Comparison of CPR quality and rescuer fatigue between standard 30:2 CPR and chest compression-only CPR: a randomized crossover manikin trial. *Scand J Trauma Resusc Emerg Med*. 2014;22:59-67. doi:10.1186/s13049-014-0059-x.
41. Kim H, You JS, Chung SP. Influence of rescuer strength and shift cycle time on chest compression quality. *Signa Vitae*. 2017;13(1):70-74. doi:10.22514/SV131.052017.29.
42. Min MK, Yeom SR, Ryu JH, et al. A 10-s rest improves chest compression quality during hands-only cardiopulmonary resuscitation: A prospective, randomized crossover study using a manikin model. *Resuscitation*. 2013;84:1279-1284. doi:10.1016/j.resuscitation.2013.01.035.
43. Lin C-C, Kuo C-W, Ng C-J, Li W-C, Weng Y-M, Chen J-C. Rescuer factors predict high-quality CPR—a manikin-based study of health care providers. *Am J Emerg Med*. 2016;34:20-24. doi:10.1016/j.ajem.2015.09.001.
44. Trowbridge C, Parekh JN, Ricard MD, Potts J, Patrickson WC, Cason CL. A randomized cross-over study of the quality of cardiopulmonary resuscitation among females performing 30:2 and hands-only cardiopulmonary resuscitation. *BMC Nurs*. 2009;8:6-18. doi:10.1186/1472-6955-8-6.
45. López-González A, Sánchez-López M, Garcia-Hermoso A, López-Tendero J, Rabanales-Sotos J, Martínez-Vizcaino V. Muscular fitness as a mediator of quality cardiopulmonary resuscitation. *Am J Emerg Med*. 2016;34:1845-1849. doi:10.1016/j.ajem.2016.06.058.
46. Borg G. Psychophysical scaling with applications in physical work and the perception of exertion. *Scand J Work Environ Health*. 1990;16(suppl 1):55-58. doi:10.5271/sjweh.1815.