THE RELATIONSHIP OF INJURY AND CARDIORESPIRATORY FITNESS AND EFFECTIVE CARDIOPULMONARY RESUSCITATION IN FIREFIGHTERS

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

By

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

Major Department:
Health, Nutrition, and Exercise Science

May 2018

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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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

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ABSTRACT

Quality cardiopulmonary resuscitation (CPR) is an essential component in cardiac arrest survival. Research indicates that a first responder's performance is generally inadequate due to many factors including fatigue or distractions. One factor that has not been studied is prior musculoskeletal injuries. This study aims to determine if a correlation exists between firefighter's CPR performance, fatigue, and prior musculoskeletal injuries. Twenty-nine urban firefighters participated. Researchers were supplied with basic demographics and a self-reported musculoskeletal injury history through secondary injury questionnaires. Participants performed five rounds of single-rescuer CPR followed by a graded exercise test (GXT), then another set of five rounds of CPR. Results indicated that BMI was a predictor for overall CPR score pre-GXT, and BMI and back pain were indicators for full chest recoil percentage pre-GXT. We conclude that an increased BMI may positively impact CPR performance, and the presence of back pain may have a negative impact on performance.

ACKNOWLEDGEMENTS

I would like to take this opportunity to acknowledge the individuals involved in the completion of this thesis. Initially, I would like to thank my advisor, Dr. Katie Lyman, for giving me this opportunity to work with a population that is so near and dear to my heart. Thank you for compelling me to complete this research and encouraging me when it seemed overwhelming. Thank you for your guidance through this process and all the hard work you put into this thesis. I would also like to thank my committee, Chief Steve Dirksen and Dr. Bryan Christensen, for being a part of this process as well. Thank you to the Fargo Fire Department for participating in this study and giving your full effort. It was a pleasure working with all of you. I would also like to thank Dr. Christi McGeorge for her expertise and performing the statistical analyses for this project. Without you, I think we would still be trying to do it ourselves. I would also like to thank my parents. Thank you for supporting me no matter what crazy idea I get into my head or where I want to move in the country. Thank you for always listening when I get stressed. Thank you for making viable suggestions and always encouraging me to keep going. Last, but certainly not least, thank you to the brave first responders across the country who put their lives on the line daily to help people on their darkest days. You all are the driving force behind this project.

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CHAPTER 1. INTRODUCTION

1.1. Overview of the Problem

Cardiopulmonary resuscitation (CPR) is a potentially lifesaving task that, if done correctly, can increase the likelihood of survival from a cardiac event. Unfortunately, there is research that indicates emergency medical professionals who are trained extensively in proper CPR form, are inadequate in their overall performance (Ashton, 2002; Geddes et al., 2007; Liberman et al., 1999; Noordergraaf et al., 2006; Ochoa et al., 1998. Thoren et al., 2001). In fact, 50% of pre-hospital care workers (police, firefighters, and EMS) believed they were proficient in all aspects of CPR, but only 1% met all the criteria (Liberman et al., 1999). This diminished ability to perform proper CPR can be attributed to many factors, including improper technique (Nolan, 2014; Wik, 2005), distractions (Kim et al., 2015; Thoren et al., 2001), poor training (Fernandez et al., 2015), and, hypothetically, prior musculoskeletal injuries.

The relationship between previous musculoskeletal injury and the ability to perform high-quality CPR has received the least amount of focus in the existing and available literature. Although not all injuries sustained by first responders occur while on the job, a prior injury can easily be exacerbated once the individual has returned to work and is required to perform work-related duties. Firefighters are often the first of the emergency response teams to arrive to a medical emergency (Hoyer & Christensen, 2009). Because firefighters are expected to perform basic life support skills (BLS), including CPR, until advanced medical personnel arrive, prior musculoskeletal injuries may be exacerbated or may limit their ability to perform high-quality medical interventions.

1.2. Statement of Purpose

The primary purpose of this study was to determine if there was a relationship between orthopedic injuries of career firefighters and their ability to perform CPR. The secondary purpose was to analyze the relationship between cardiorespiratory fitness and prior musculoskeletal injury of firefighters and their ability to perform high-quality CPR.

1.3. Research Questions

This study was guided by the following research questions:

Q1: Is there a statistically significant correlation between prior orthopedic injuries sustained by firefighters and their ability to perform effective CPR?

Q2: Does performing a VO_{2max} protocol influence prior orthopedic injuries and a firefighter's ability to perform effective CPR?

1.4. Limitations

This research study contained limitations as the result of multiple variables. The first limitation was that only male participants were included in the study. The chosen fire department for this study had only males on active duty, which made the research results not generalizable to female firefighters. An additional limitation was that this study included participants in the age range of 20 to 55 years old. Specifying a specific age range limited the application of results to firefighters within these parameters. Lastly, firefighters who were unable to perform active-duty tasks due to a current injury or medical condition were excluded. Although the gathered data could be relevant to the proposed research questions, the risk to their career and general well-being outweighed the significance of this study.

1.5. Delimitations

Due to limited resources, there were a few variables the research team controlled. Firstly, we chose to limit the study to firefighters only; despite the lack of research altogether on any groups and the relationship between CPR performance and orthopedic injuries. Another delimitation involved in this study was the decision to recruit firefighters from only one department. This limited research results to only urban, career firefighters. At the time of current study, the recommendation for professional rescuers performing CPR involved 30 chest compressions and two rescue breaths. Due to the fact participants were wearing a mouthpiece to collect metabolic information for the duration of the study, they were instructed to use a bag valve mask to deliver the rescue breaths. Finally, based on an exhaustive literature review, we chose these particular questionnaires based on the validity and reliability results from previous researchers. These questionnaires were also chosen for their concise manner as participants were asked to fill out multiple activity-based questionnaires and would likely lose focus if the surveys were lengthy. Although many musculoskeletal injury questionnaires exist that look at multiple factors, we chose ten to accurately represent and understand the musculoskeletal injury history of each firefighter.

1.6. Assumptions

Because participants completed health history questionnaires and injury history questionnaires, we assumed that they completed the forms honestly and to the fullest extent of their knowledge. We also assumed that they performed CPR to their best ability as well as gave maximal effort on the Balke-Ware VO_{2max} protocol to produce volitional fatigue.

1.7. Variables

The independent variables in this study are prior musculoskeletal injury and baseline cardiorespiratory fitness. The dependent variables were seven areas (mean compression rate, number of compressions with full chest recoil, mean depth of compressions, mean chest compression depth, compression/depth ratio, and compression fraction) of cardiopulmonary resuscitation (CPR) which were collected by the Resusci Anne® QCPR.

1.8. Definitions

Cardiopulmonary resuscitation (CPR): A procedure to support and maintain breathing and circulation for an infant, child, or adult who has stopped breathing (respiratory arrest) and/or whose heart has stopped (cardiac arrest). (American Heart Association, 2017).

Sudden cardiac arrest (SCA): Unexpected circulatory arrest, usually due to a cardiac arrhythmia occurring within an hour of the onset of symptoms, in whom medical intervention reverses the event (Kong et al., 2011, p. 799). The abrupt loss of heart function in a person who may or may not have diagnosed heart disease. The time and mode of death are unexpected and occur instantly or shortly after symptoms appear (American Heart Association).

Sudden cardiac death (SCD): Death from an unexpected circulatory arrest, usually due to a cardiac arrhythmia occurring within an hour of the onset of symptoms (Kong et al., 2011, p. 799). Sudden, unexpected death caused by loss of heart function (Cleveland Clinic, WebMD)

Significant injury: An injury in which an individual has sought treatment from a doctor, chiropractor, physical therapist, etc. and/or has restricted their ability to perform daily or work-related tasks.

1.9. Significance of Study

To the knowledge of the research team at North Dakota State University, there is no research which has investigated the correlation between orthopedic injuries and CPR performance. Examining a relationship between prior injuries of firefighters and their ability to perform CPR could lead to evidence-based protocols and policies to protect the well-being of firefighters as well as protect the general public from receiving low-quality medical interventions from firefighters who are ill-prepared to participate in job-specific duties. This research is important to ensure firefighters have properly recovered from their injuries before returning to work, so they can perform their job to the fullest extent. The likelihood of an individual surviving from a cardiac event increases if the CPR delivered is high quality (Nolan, 2014), but can drop significantly if even one component of CPR is subpar. The importance of detecting how strong the correlation orthopedic injuries and cardiorespiratory fitness has with CPR performance is essential for the overall well-being of the community in which firefighters serve.

CHAPTER 2. LITERATURE REVIEW

There is no research which analyzes the relationship between injuries sustained by firefighters and the effect those injuries have on their ability to perform medical interventions, such as cardiopulmonary resuscitation (CPR). Previous researchers have analyzed components of CPR conducted by health care professionals (Ashton et al., 2002; Higdon et al., 2006; Noordergraaf et al., 2006; Rottenberg, 2013; Shultz et al., 1995; Thoren et al., 2001; Wutzler et al., 2014), but researchers have yet to investigate factors affecting performance. Previous or current musculoskeletal injuries have a significant impact not only on daily tasks, but work performance, which for firefighters can literally mean life or death of the victim. Therefore, as a matter of public safety, research which investigates the quality of CPR is essential in order to improve the mortality rate for cardiac arrest victims.

2.1. Sudden Cardiac Arrest and Death

2.1.1. Definitions

There are conflicting definitions of sudden cardiac arrest (SCA) and sudden cardiac death (SCD) (Kong et al., 2011). Although there is a wide variance among researchers and healthcare professionals, the most commonly accepted definition of SCA is “the abrupt loss of heart function in a person who may or may not have diagnosed heart disease. The time and mode of death are unexpected and occur instantly or shortly after symptoms appear” (American Heart Association). If left untreated, or treated improperly, SCA can result in SCD, which is defined as “sudden, unexpected death caused by loss of heart function (Cleveland Clinic, 2017). Unfortunately, the definitions are often used interchangeably, despite having very distinct differences (Kong et al., 2011) with SCD being permanent, and SCA being reversible.

The two most common electrical causes of SCA, often resulting in SCD, are ventricular fibrillation (VF) and pulseless electrical activity (PEA). VF is defined as an arrhythmia in which the lower two chambers of the heart beat out of rhythm resulting in the inability to pump blood efficiently (Chugh et al., 2008). While VF is a strong, sporadic rhythm, PEA is the opposite. Its definition is an arrhythmia that when read on a heart monitor should produce a pulse in the patient but does not. There is electrical activity, however the heart is either not contracting or there is insufficient blood pumping through it (Chugh et al., 2008). Both arrhythmias can result in a major cardiac event and reportedly cause half of cardiac-related deaths (Kong et al., 2011; Papadakis, 2010; Straus et al., 2004).

2.1.2. Epidemiology

In a systematic review performed by Kong et al. (2011), an accurate estimate of the annual occurrence of SCD attempted to draw an incidence rate for the general population through multiple sources. The inclusion criteria for the systematic review required that the study was performed in the United States and was original research, as opposed to reports of SCD from alternative sources. The inclusion criteria yielded six peer-reviewed manuscripts from 1989 to 2008. Of these six studies, Kong et al. (2011) reported an annual incidence rate of SCD ranging from 180,000 to 450,000. One of the resources cited in Kong et al.'s study used registry data from eight different sites in the United States to create an annual incidence rate for the entire nation (Nichol et al., 2008). Two studies estimated incidence of SCD based on smaller community-based studies (Chugh et al., 2004; Cobb et al., 2002). The remaining three used national- level data for their estimates (Escobedo & Zack, 1996; Gillum, 1989; Zheng et al., 2001) with one source using data reported to the National Center for Health Statistics, which received data from only 40 states (Gillum, 1989).

The published systematic review by Kong et al. (2011) referred to additional methodological concerns from the six articles which met the inclusion criteria. In addition to the wide variety of locations of the investigations, the definition for SCD also varied among the six studies with one including the phrase "survivors of cardiac arrest" (Kong et al., 2011, p. 796). This further confuses readers because sudden cardiac arrest is a reversible event, where sudden cardiac death is not (Kong et al., 2011). Two studies specified their definition of SCD as "death attributable to ischemic or coronary heart disease" (Kong et al., 2011, p. 796), while the other four used a general definition of "death from a cardiac or cardiovascular etiology" (Kong et al., 2011, p. 796). This broadened definition makes it difficult to attribute cause of death to specific cardiac conditions, which poses problems for researchers attempting to establish statistics and understand the etiology of specific cardiac conditions. Some of the research also used specific age ranges and generalized them to the entire population, further varying their statistics. The wide gap in incidence rates among six controlled studies shows that further research collection methods need to be developed to better understand how SCD truly effects the general population.

According to the American Heart Association, the 2016 statistics for out-of-hospital cardiac arrest (OHCA) in the United States is 350,000 per year. Unfortunately, there is no clear explanation as to how the data were gathered, whether via national registry or approximations. This discontinuity creates barriers when trying to find statistics that are generalizable and usable for analyzing trends in epidemiology.

Many incidences of SCA/SCD are unwitnessed, which means that SCD cannot always be named the cause of death (Straus et al., 2004). The rate of unwitnessed SCD was found to be 39.2% in one study, while another found that 40-50% of all incidences were unwitnessed (Chugh et al., 2004). Because the incidents were unwitnessed, many of the reports on SCA/SCD did not include them in the analysis due to lack of accuracy of true cause of death. This poses a threat to the validity of data because the cause of death could possibly be marked as SCD when alternative causes of death are to blame. Mismarked data leads to an over-inflation of incidence by 200-300% when using retrospective analysis to obtain data (Arking et al., 2001). The complicated inclusion data also contributes to the large variance in annual occurrence (Chugh et al., 2008). Even though the actual incidence rate is unclear, there are trends that have been noted by researchers.

2.1.2.1. Age and Gender. When analyzing incidence of SCA and SCD, specific populations have been identified as having remarkably higher rates than others. According to Chugh et al. (2008), there are two well-established peaks in age-related SCD; one during infancy and the other between 75 and 85 years old. Few studies recognize the peak in infancy due to the causes of death being attributed to etiology such a sudden infant death syndrome (SIDS) or congenital heart malformations. However, researchers' reference that advancing age is a significant factor in SCD with many unwitnessed incidences of SCD occurring in the older population (Papadakis et al., 2010; Straus et al., 2008). This peak could be attributed to older individuals living alone or having underlying cardiac health issues (Straus et al., 2008).

Age and gender statistics can be independent of one another when presenting evidence, but there are also important relationships that have been established between the two (Straus et al., 2008). Researchers who conclude gender as a factor would agree males have a higher incidence of SCD than females across almost all ages, but the reported statistics vary depending on the researchers (Chugh et al., 2008; Straus et al., 2008). Straus, et al. (2008) reported the incidence rate for males was 1.12/1000 people, compared to females which was .75/1000 people per year. Two studies support findings that show higher rates among males, indicating they make up 63-68% of all cases of SCD among middle-aged individuals (Behr et al., 2003; Wisten et al., 2002). However, a study from Chugh et al. (2008) offers conflicting information to the above findings. Chugh et al.'s study, in the same systematic review, details a higher incidence of SCD in younger females, with 50% of post-mortem analysis suspecting SCD as an undetermined etiology cause of death compared to just 24% of males in the same age range. These contradictory statistics support how difficult it is for researchers to determine a generalizable incidence rate across all populations.

2.1.2.2. Physical Activity Levels. Physical activity levels of victims have shown little to no effect on the incidence of SCA/SCD (Chugh et al., 2008; Stecker et al., 2016). Reddy et al. (2009) analyzed over 300 SCA patients and divided them into five groups based on activity at the time of the incident: sleeping, light activity, moderate activity, heavy activity, and sexual activity. Eighty percent of all subjects were engaged in light or no physical activity when the event occurred making engagement in physical activity a non-significant factor for predisposition to an SCA/SCD event. Similarly, a study by Stecker et al. (2016) analyzed the active population. Of the 357 cases, 69% of them were competitive athletes, and the remaining 31% engaged in at least 180 minutes of physical activity a week. Researchers found 40% of all events of SCD occurred at rest and of those 40%, 81% occurred without any preceding symptoms. Physical activity does not necessarily place an individual at risk for a cardiac event, but rather exposes any underlying conditions an individual may have which could predispose them to a cardiac event. Upon further investigation, many of these individuals who were seemingly healthy had underlying conditions, which predisposed them to SCA/SCD (Stecker et al., 2016).

2.1.2.3. Electrical & Structural Abnormalities. Cases of SCA/SCD are generally caused by electrical or structural abnormalities and disease (Stecker et al., 2016). As previously mentioned, VF is one of the most common arrhythmias present during the initial analysis of a victim. The percentages of incidence have fluctuated over the years with early studies indicating 75-84% of patients had an initial rhythm of VF, but another study reported a lower percentage of approximately 41% (Cobb et al., 1999). Studies performed between 1980 and 2000 show a decrease in the occurrence of VF by 56% with some researchers speculating that now only 26% of cases start as VF. This shift is thought to be attributed to a decline in incidence of VF due to coronary health awareness (Chugh et al., 2008).

Structural disease and abnormalities also play a role in the occurrence of SCA/SCD. Eighty percent of SCD victims have signs of coronary artery disease (CAD), making it the most commonly associated condition with SCD (Chugh et al. 2004). CAD occurs when fatty deposits called plaques begin to narrow the arteries of the heart causing a reduction in blood flow (Fox et al., 2004). If these plaques break away from the artery wall and significantly or totally occlude the arteries, the result is acute myocardial infarction (i.e. heart attack) (Fox et al., 2004). If the occlusion is significant, or the heart attack is left untreated for a prolonged period of time, SCA can occur, which can result in SCD.

With only 13-20% of people who have CAD ever experiencing a significant cardiac event, other structural abnormalities present higher incidence rates of SCA/SCD (Kannel et al., 1987). One such abnormality is hypertrophic cardiomyopathy (HCM). HCM is defined as ventricular hypertrophy or thickening of the ventricular muscle wall. HCM makes up the largest portion of all cardiomyopathy conditions affecting 1 in 500 people and an annual mortality rate ranging from 0.5 to 3% (Papadakis et al., 2010). Many times, this condition can go undiscovered until after SCA/SCD has occurred, which makes it the most common cause of death in young, healthy athletes (Papadakis et al., 2010). Other, less frequently occurring cardiomyopathies can cause SCA/SCD, such as arrhythmogenic right ventricular cardiomyopathy (ARVC), which affects 1 in 1000 people (Basso et al., 2009). Because many of these conditions are never detected unless there are outward symptoms; thus, individuals may not receive the specialty care that is required in order to prevent an SCA or SCD event. With so many different causes of SCA/SCD, it is imperative all contributing factors are clearly defined and well established to help develop strategies to prevent or treat a cardiac condition in order to increase survival rates.

2.2. Current American Heart Association Guidelines

The American Heart Association (AHA) Guidelines is a resource for rescuers to adhere to when needing to provide cardiopulmonary resuscitation (CPR) and emergency cardiovascular care (ECC). The Guidelines are reviewed every five years ensures the best medical practices are being performed for victims of SCA. The 2015 Guidelines included updates and changes from the 2010 Guidelines for adult basic life support (BLS) CPR for both lay rescuers and first responders. Researchers analyze the important aspects of early intervention, compression rate, compression depth, chest recoil, and minimizing interruptions. The findings are then interpreted and compiled into easy-to-read guidelines to increase the quality of CPR which, in turn, can increase the survival rate.

2.2.1. Chest Compressions & Rescue Breaths

More emphasis has been placed on starting chest compressions as soon as the signs of unresponsiveness have been recognized. A change has also been made for lay rescuers to perform chest compressions only as opposed to earlier guidelines which requested compressions and rescue breaths (AHA Guidelines, 2015). The recommendation for lay rescuers to refrain from rescue breaths stems from research that has revealed that even trained professionals can struggle to give effective rescue breaths (Higdon et al., 2006; Thoren et al., 2001.) In a study done by Higdon et al. (2006), it was reported that certified emergency medical technicians (EMT's) took, on average, 10 seconds to deliver rescue breaths. The AHA requirements at the time of the study required two rescue breaths be delivered over only four seconds. The same study reported lay rescuers took roughly 16 seconds to deliver the same breaths, which results in less time performing chest compressions.

A similar study investigated the efficiency of 10 nurses and nursing students who used ventilation masks during CPR to deliver rescue breaths (Thoren et al., 2001). The study analyzed inflation rate, speed, volume, and number of ventilations per minute. Ninety percent of all inflations were too fast, 71% delivered too little oxygen, and only 6.5% of overall inflations were considered correct. As previously stated, healthcare professionals who perform CPR on a regular basis may deliver ventilations incorrectly, which prompted the new recommendation by the AHA that the rescuer should start compressions as soon as possible and not break for breaths.

Wang et al. (2009) investigated paramedics' ability to intubate a victim and the time it took away from performing chest compressions. On average, it took paramedics 109.5 seconds to successfully intubate a victim with some paramedics taking up to seven minutes. Intubation accounted for approximately one fourth of all chest compression interruptions alone, taking away time spent circulating blood through the victim's body. Some rescuers have even eliminated the use of rescue breaths, and perform 200 continuous chest compressions with passive oxygenation, stopping only for rhythm analysis and defibrillation (Koster, 2015). Some departments that changed to this CPR procedure recorded an increase in the rate of survival to discharge from 1.8% to 5.4%. The 2015 update suggested rescuers could perform three rounds of 200 uninterrupted compressions with passive oxygenation. With chest compressions being so key to survival, updated guidelines on proper CPR are needed to better improve survival rates.

2.2.2. Chest Compression Rate

Compression rate guidelines have been updated to give concrete lower and upper limits to optimize the chances of survival. Per the AHA 2010 guidelines, a minimum of 100 compressions per minute was considered adequate. In the 2015 update, the new recommendation is 100-120 compressions per minute. This set of guidelines was changed because higher compression rates have been linked with higher survival rates (AHA Guidelines, 2015). One such study that helped move towards a higher number of compressions per minute reported higher compression rates directly linked to a higher chance of survival, while lower compression rates resulted in a significantly lower chance of survival (Abella et al., 2004). The upper limit is new to the guidelines based on a study cited by the AHA Guidelines which presented evidence that overly rapid chest compressions could affect compression depth, which can ultimately diminish the amount of blood flow to the brain (AHA Guidelines, 2015).

Although the increased chest compression rate increases the likelihood of survival, it is harder to maintain and induces fatigue sooner in rescuers (Yang et al., 2014). Yang et al. (2014) noted that although the higher compression rates induced fatigue quicker than previous guidelines rates, the overall quality of compressions was superior and potentially contributed to the increased survival rates.

Compression rates can be negatively affected by interruptions, which necessitated the new guidelines also emphasize that interruptions for opening airways, rescue breaths, and AED analysis be minimized. In a study performed by Higdon et al. (2006), researchers analyzed EMT's ability to give rescue breaths. The results displayed that not one single subject could perform rescue breaths and keep their compression rate above 80 compressions in a minute. Without the rescue breaths, 68% of subjects obtained 80 or more compressions in a minute. Similarly, an animal study showed a 100% return of spontaneous circulation in swine that received 80 compressions or more per minute (Yu et al., 2002). Only 10% of swine survived if the compression rate was below 80. Despite these studies analyzing results based on older AHA guidelines of only 80-100 compressions per minute, the results still support current guidelines using increased rates of compressions and further verify that minimizing interruptions can lead to increase survival rates.

2.2.3. Chest Compression Depth

The updated AHA recommendation for chest compression depth was also clarified from a minimum of two inches of depression of the chest to a range including a minimum of two inches but no more than 2.4 inches (AHA Guidelines, 2015). In the Guidelines, the AHA states that this upper limit was placed because “one small study,” as quoted by the AHA, suggesting there were non-life threatening adverse effects that could occur if the chest compressions were too deep (AHA Guidelines, 2015). Original research conducted by Thoren et al. in 2001 investigated CPR performance by nurses and nursing students. The researchers reported the average depth of compression was 4.7 centimeters (1.8 inches). The guidelines at the time of the study stated to compress the chest 3.81 centimeters to 5.08 centimeters (1.5 to 2 inches), which meant that the average at the time was considered adequate. The researchers also noted that 40% of all compressions were deeper than five centimeters, which was considered too deep. If the 2015 update was converted into centimeters (5.08-6.10 centimeters), those that fell in the “too deep” category would be considered adequate, while those that fell in the “correct” category would now be considered insufficient. Although these changes may seem minor, they are essential to keep blood circulating through the heart and more importantly to the brain.

2.2.4. Chest Compression Fraction

In the updated Guidelines, the AHA uses the term "chest compression fraction" to describe the amount of time spent performing chest compressions out of the entire time spent working on the patient (Nolan, 2014). This concept applies more to healthcare professionals who are performing other lifesaving tasks such as ventilations and setting up an AED versus a lay rescuer who is advised to perform chest compressions only (AHA Guidelines, 2015). The recommendation on minimizing interruptions in chest compressions has been given a target number versus a more open-ended recommendation from the 2010 guidelines. The minimum chest compression fraction should be 60%; meaning if CPR is performed for 10 minutes, at least six of those minutes should be spent performing chest compressions.

A 2014 study by Nolan supports that 60% chest compression fraction minimum through data collected by the North American Resuscitation Outcomes Consortium (ROC). The research concluded that patients whose chest compression fraction was 60% or higher had a three times greater chance of surviving the trip to the hospital than patients with a chest compression fraction of 20% or lower. Interruptions during CPR are inevitable in the pre-hospital setting. Fatigue has been a prominent factor affecting CPR performance. One study performed by Ochoa et al. (2008) found correct compression performance diminished from 79.7% in the first minute to 24.9% in the second minute, and down to 18.5% by the end of five minutes. Rescuers were also instructed to announce when they felt that fatigue was affecting their performance. The average time for all rescuers was 186 seconds, which compared to the data, shows that rescuers are unaware of their diminished performance. Compression rates can be negatively affected by interruptions, thus the new guidelines also emphasize that interruptions for opening airways, rescue breaths, and AED analysis be minimized.

2.2.5. Chest Recoil

The last concept highlighted in the American Heart Association Guidelines for CPR and ECC discusses full chest recoil and its importance to ensure optimal blood circulation during CPR. Chest recoil is defined as “the return of the sternum to its natural position during the decompression phase of CPR” (AHA Guidelines, 2015, p. 9). Complete recoil is important because obtaining full recoil creates negative pressure in the chest cavity, which helps draw blood towards the heart through the veins (AHA Guidelines, 2015). Leaning on the chest wall during CPR occurred in 12% of incidences of an in-hospital study, indicating it often occurs when the rescuer begins to fatigue (Nolan, 2014). The Guidelines only updated the wording on chest recoil to properly define what “full recoil” means. In 2010, the guidelines stated, “rescuers should allow complete recoil of the chest after each compression, to allow the heart to fill completely before the next compression” (AHA Guidelines, 2015, p. 9). The current 2015 Guidelines now state, “It is reasonable for rescuers to avoid leaning on the chest between compressions, to allow full chest wall recoil for adults in cardiac arrest (AHA Guidelines, 2015, p. 9). This change advises how to obtain full chest recoil and avoids any personal interpretations to the definition.

2.3. EMS and Bystander CPR Performance

2.3.1. EMS CPR Performance

There has been some research on CPR performance with in-hospital staff, including doctors, nurses, and medical residents but unfortunately, there is not the same amount of research for out-of-hospital CPR performance by EMS personnel. It is difficult to obtain accurate data in an out-of-hospital setting and attempting to simulate an emergency environment is complex for researchers. Although the available research is limited in scope, it does indicate the challenges faced by lay public, or bystanders of an emergency, and trained first responders.

There are many factors that can influence patient outcomes following a cardiac event that are present even before emergency medical providers reach the scene of an emergency. As Nolan indicated in his 2014 study, some bystanders did not respond appropriately to a cardiac emergency with 6.4% of people calling someone other than EMS first, such as friends or relatives. The time that it takes for a bystander to recognize the symptoms of a cardiac event and activate EMS could mean life or death for the victim. These critical minutes spent not providing appropriate treatment make the chances of survival diminish significantly (Nolan, 2014). Once on the phone with a dispatcher, the bystander can help provide appropriate clues to the victim's condition, which assist dispatchers in relaying correct information to rescuers. Unfortunately, identification of the victim's condition is not always a simple task. On average, it took dispatch 75 seconds to recognize the victim was suffering from cardiac arrest (Lewis et al., 2013). Reasons that caused this significant delay included the caller not being with the victim, phone connection lost, callers refusing/could not asses victim, caller failed to recognize agonal respirations, and callers providing conflicting information to dispatch. All of the aforementioned delays in care have the potential to decrease the chances of survival from a cardiac event.

Another unique issue first responders face is the interaction with distressed friends and family members. One study conducted in Korea cited "complaints of family members" as the second most common obstacle faced on-scene for EMTs (Kim et al. 2015, p. 844). The study consisted of two parts, the first being an email survey that was completed by 254 EMTs and the second including 35 minutes of two-person CPR with simulated "family members," followed by a survey. Both the email survey and the post-CPR survey had “complaints of family members” ranked second for obstacles (62.8% and 58.1%, respectively). This response followed closely behind the most popular response of “fear of decrease in CPR performance” (Kim et al., 2015, p. 844). These results indicate physical strength and skill may not be the only factors involved with successful CPR performance.

Another influential factor on CPR performance for first responders is demographic qualities of the rescuer. Lin et al. (2016) conducted a study who recruited EMTs to analyze different rescuer health factors and their relationship with CPR performance. Researchers concluded that the higher a rescuer’s BMI and average total exercise per week predicted higher quality CPR. Generally, the heavier a person is, the more body weight they can use to get full compressions. The group that performed high-quality CPR had an average BMI of 23.6 and exercised an average of 300 minutes per week. This point is conferred by Lin citing another study performed by Hasegawa et al. (2014) reviewing the CPR performance between lighter and heavier groups of nurses. The results showed the lighter group became easily fatigued and the CPR quality declined over the five-minute test.

Looking more at physical fitness and less at body composition, researchers examined ventilatory threshold and muscle strength of rescuers and the impact each one had on CPR performance. Rescuers with a higher ventilatory threshold had higher quality CPR in the first five minutes than rescuers who had lower thresholds, but this did not extend beyond the time frame. After the first five minutes, rescuers with a higher maximal isometric elbow extension performed better in the later minutes of the duration of CPR (Hansen et al., 2012). Results indicated higher quality CPR was significantly correlated with the two. Ventilatory threshold and CPR performance had a correlation coefficient of 0.67 and isometric elbow extension had a correlation coefficient of 0.55, which were both larger than any other factors, and above the accepted rate. These results help to establish the idea that overall physical fitness, including cardiovascular health and muscular strength, are important factors in rescuers performance.

2.3.2. Bystander CPR Performance

Cardiac event survival rates not only depend on the quality of CPR, but also the time it takes to initiate CPR. Making a quick response is crucial to the victim. Bystander initiated CPR becomes essential in out-of-hospital cardiac arrest cases to increase survival rates. Hansen et al. (2015) examined data collected from counties across South Carolina and found 31.8% of victims who had a spontaneous return of circulation (SRC) received initial care from a bystander. Note that SRC does not necessarily mean that the patient survived the cardiac event, but while CPR was being administered, the heart began to beat again on its own. Furthermore, the bystander SRC rate was higher than those victims that received initial care from first responders (27%) and EMS (26.3%), which was attributed to the quicker response of the bystanders who were present at the time of the event. Unfortunately, bystanders are not always trained or willing to perform a medical intervention, but bystander intervention has been on the rise due to “dispatch-assisted” CPR. Three studies have noted an increase in bystander CPR once a “dispatch-assisted” CPR program has been implemented (Hansen et al., 2015; Song et al., 2014; Wissenberg et al., 2013). One study based in North Carolina analyzed the effects of the HeartRescue Project that included CPR courses offered at community centers, school staff training on CPR and AED use, and specialized training for dispatchers to better recognize cardiac arrest descriptions, as well as how to give CPR instructions over the phone (Hansen et al., 2015). Researchers noted an increase in cardiac event SRC rates from a baseline of 39.3% to 49.4% when reanalyzed three years after implementation.

Other countries have different standards in medical care, which may have an impact on their outcomes. Denmark had the next closest SRC rate after the United States with a baseline of 21.1% of bystander implemented initial care before dispatch-assisted CPR. This SRC rate doubled to 44.9% after nine years of the program (Wissenberg et al., 2013). South Korea had one of the lowest baseline rates, starting at 5.7% (Song et al., 2014). Researchers in South Korea reported an increase to 12.4% after three years of the dispatch-assisted CPR program. All of these studies also found an increase in survival-to-discharge rates, correlating with initiating the dispatcher assisted CPR program. Survival to discharge from the hospital rates in South Carolina rose from 8.9% (when care was initiated by bystanders) to 10.5% (Hansen et al., 2015), 3.5% to 10.8% in Denmark (Wissenberg et al., 2013) and 7.1% to 9.4% in South Korea (Song et al., 2014). These data sets present the importance of initiating CPR as soon as possible, even if it is by an untrained bystander.

2.4. CPR Related Injuries

Although no link could be found between previous musculoskeletal injuries affecting CPR performance, there is literature that has determined that CPR may cause injuries (specifically back injuries). One researcher analyzed both EMTs and nurses who performed CPR and found similar results between the two groups (Jones, 2004; Jones & Lee, 2005). CPR performed by one person could last for nearly thirty minutes in both groups (32 minutes for EMT's and 27 minutes for nurses), with nearly all instances involving the delivery of chest compressions on a bed. Seventy percent of nurses and 60% of EMTs said their legs hung off the side of the bed while performing CPR. An unstable position could predispose someone to back issues, and the added movement of the ambulance or turning of the head to read the ECG monitor increases the chances of injury. Eighty percent of nurses and 96% of EMT's complained of back discomfort while performing CPR, and about half of both groups considered this improper positioning as the cause of their back injuries (Jones, 2004; Jones & Lee, 2005).

Studnek et al. (2010) analyzed survey responses from EMS workers who self-reported back pain. About half (50.5%) reported pain in their back at least once in the previous two weeks. The pain was not specified if it was from work-related tasks, but it did note that 65.8% of responders with back pain were classified as overweight or obese. Being a very physically demanding job, especially when performing CPR, EMTs with prior pain or predisposing conditions could potentially raise the risk of injury and affect their CPR performance.

2.5. Conclusion

After an exhaustive literature review, no research was found that analyzed the relationship between prior musculoskeletal injuries and CPR performance in any context. One would hypothesize prior injury could influence a rescuer's ability to maintain proper form and provide consistent, high-quality medical interventions. Three researchers have examined the reverse relationship, analyzing if CPR can lead to injuries in first responders and in-hospital staff, with compelling results that performing a whole-body medical intervention, such as CPR, can result in a musculoskeletal injury (Jones, 2004; Jones & Lee, 2005; Studnek et al., 2010). Establishing this relationship between musculoskeletal injury and the ability to perform CPR is essential to provide evidence-based recommendations for future AHA Guidelines.

CHAPTER 3. METHODOLOGY

The primary purpose of this study was to investigate the relationship between prior orthopedic injury, as self-reported by firefighters, and the ability to perform cardiopulmonary resuscitation (CPR). The secondary purpose was to evaluate the potential for exacerbation of musculoskeletal injuries following firefighter participation in a VO_{2max} protocol. Although previous research has provided evidence that CPR is often performed incorrectly (Ashton et al., 2002; Liberman et al., 1999; Rottenberg, 2013; Nolan, 2014; Thoren et al., 2001; Wang et al., 2009), exploring prior injuries in firefighters can assist researchers with providing solutions to resolve the high mortality rate of the general public following a cardiac event. In order to address the gap in literature, this study used qualitative measures through the use of injury questionnaires and quantitative measures with the use of a medium-fidelity CPR manikin (Resusci Anne® QCPR) and measuring VO_{2max}. In order to answer what impact orthopedic injuries and cardiorespiratory fitness have on firefighter CPR performance, this study used qualitative and quantitative measures to determine an individual's disability level and that level's effects CPR performance data. These two sets of raw data were then compared and analyzed for any potential relationships.

3.1. Purpose

The primary purpose of this study was to determine if there was a relationship between orthopedic injuries of career firefighters and their ability to perform CPR. The secondary purpose was to analyze cardiorespiratory fitness of firefighters while performing CPR. The research questions that guided this study are as follows:

Q1: Is there a statistically significant correlation between prior orthopedic injuries sustained by firefighters and their ability to perform effective CPR?

Q2: Does performing a VO_{2max} protocol influence prior orthopedic injuries and a firefighter's ability to perform effective CPR?

3.2. Participants

Thirty male participants were recruited from a fire department in a mid-sized, Midwestern, city. The fire department which agreed to participate in the study currently had no female firefighters in a position other than administration; therefore, only males were analyzed in this study. Participants were recruited through informational meetings held at the fire stations. Each participant was an active member of the City of Fargo Fire Department between the ages of 20-55 years old. If the participant had a current injury or medical condition which precludes the firefighter from performing active, on-duty tasks; pervious medical concern from prior graded exercise tests; or, inability to perform treadmill walking with issued turnout gear, he was not able to participate in the study.

3.3. Procedures

Prior to the start of data collection, the Institutional Review Board at North Dakota State University approved the proposed methodology. A research assistant read the informed consent and clarified any questions each participant had before he signed the document. The testing for this study was conducted in the Human Performance Laboratory (HPL) in the Bentson Bunker Fieldhouse on the North Dakota State University campus, 1301 Centennial Blvd., Fargo, ND 58102. All CPR mannequins and the VO2 max testing equipment were located in this laboratory, making it the most convenient location for all subjects and researchers to meet.

For the data collection session, participants reported to the HPL for approximately one hour. The participants completed a demographic questionnaire, the International Physical Activity Questionnaire (IPAQ), and the Extended Nordic Musculoskeletal Questionnaire (NMQ-

E). Once these questionnaires were completed, a designated research assistant analyzed the responses of the NMQ-E and distributed an additional body-part specific questionnaire in order to collect detailed information regarding the self-reported injury.

Upon completion of the secondary questionnaires, the participants had their height and weight measured, with and without turnout pants and boots on, then their waist circumference measured. Participants were then fitted with a heart rate monitor (Polar, Kempele, Finland) and a mouthpiece attached to the Parvo metabolic cart (ParvoMedics Inc., Logan, UT, USA) to be worn for all rounds of CPR and the graded exercise test. While wearing their turnout pants and boots, they were asked to perform five rounds of single rescuer CPR with ventilations on a Resusci Anne® QCPR (Laerdal Medical AS, Stavanger, Norway).

The Resusci Anne® QCPR is medium-fidelity manikin that can objectively measure CPR skills, including: raw and mean compression rate, number of compressions with full chest recoil, mean chest compression depth, compression/depth ratio, compression fraction, ventilations per minute, and ventilation volume. Next, participants performed a graded exercise test (Balke-Ware protocol. Balke & Ware, 1959) until each firefighter reported fatigue. Immediately following the graded exercise test, participants were asked to complete five additional rounds of CPR while being monitored by the Parvo metabolic cart. Following this protocol allowed researchers to analyze firefighter performance on CPR skills prior to and after an exhaustive bout of exercise.

3.4. Questionnaires and Equipment

In order to collect a basic history of previous musculoskeletal injuries, all participants completed the Nordic Musculoskeletal Questionnaire (NMQ-E). If a participant indicated he had a significant injury in which he had sought treatment for and/or had restricted his ability to perform daily or work-related tasks, he was then asked to complete a body-part specific questionnaire to establish basic, but pertinent, information about the injury. The body-part specific questionnaire was necessary to analyze the specific details of the previous injury to compare the results to other injuries and the impact injuries may have on CPR performance. In order to provide evidence-based suggestions concerning musculoskeletal injuries and CPR performance, this research is critical for the improvement of future CPR guidelines.

3.4.1. Questionnaires

Each of the following questionnaires were chosen for specific reasons for this particular study. With the nature of this study relying heavily on self-reported measures and surveys, it was essential that the questionnaires chosen were body-part specific and concise to avoid any loss of focus from the participants. Each questionnaire is no longer than thirty questions and consists of Likert-type scale questions about pain and function.

3.4.1.1. Short Form 36 (SF-36). The SF-36 is a general health survey comprised of eight commonly included components in health and injury surveys: physical functioning, role limitations because of physical health problems, bodily pain, social functioning, general mental health (psychological distress and psychological well-being), role limitations because of emotional problems, vitality (energy/fatigue) and general health perceptions (Ware & Sherbourne, 1992). The SF-36 is used to create an overview of a patient's general health, which makes much of the survey non-specific to certain conditions or injuries. Because each of the eight components are scored separately, the SF-36 can still be, and frequently is, used as a "gold standard" comparison when creating new, health history questionnaires to test validity and reliability. Many of these newly developed questionnaires are intended for use with specific body parts or conditions, and often correlate with only some of the major components of the SF-36.

For the purpose of this study, specific injury history and information was needed to analyze data and draw comparisons per the reported injury. Four components of the SF-36 analyze mental and social health and functioning, which, although important, was non- essential for the current research project. Thus, in the sections below, the validity and reliability of many of the musculoskeletal surveys have been compared to the SF-36 since it has been cited as the gold standard of health surveys (McHorney, Ware & Raczek, 1993).

3.4.1.2. Extended Nordic Musculoskeletal Questionnaire (NMQ-E). All participants were asked to complete the NMQ-E as a baseline for prior injuries. Areas of injury include neck, shoulders, upper back, elbows, wrist/hands, low back, hips/thighs, knees, and ankles/feet. Participants indicated if they had ever had any injury for which they have sought treatment and/or had restricted their work or physical activity. If yes, they would then answer a series of yes/no questions about the injury. This helped the researchers determine if further information about the specific injury should be collected.

The NMQ-E was designed by taking questions and content from previously analyzed studies that have been proven and are reliable. One study conducted by Dawson et al. (2009) determined the NMQ-E had intraclass correlation coefficients of .87 to 1.00 for all 9 body regions with a test-retest construct determining that it is of extremely sound reliability. These results indicate that the NMQ-E is a valid and reliable tool to collect data on orthopedic health history.

3.4.1.3. Disabilities of the Arm, Shoulder, and Hand (DASH). If participants indicated they had a prior injury to the shoulder, elbows, wrists/hands on the NMQ-E, they were asked to fill out the DASH questionnaire to the best of their ability. This questionnaire asks thirty questions about the individual's ability to perform various tasks on a scale of 1 (no difficulty) to

5 (unable). Twenty seven of the 30 questions must be answered to calculate a DASH score. The assigned scores for the completed responses are added together and then divided by the number of responses provided. That number is then subtracted by one, and finally multiplied by 25 to give a numerical value out of 100. The higher the calculated score, the greater the disability of the individual.

There are two optional modules that can be given to participants should the researchers require additional information about the individual's level of disability outside of tasks of daily living. One module asks work-specific tasks, and the other asks sports/performing arts specific tasks. These have been added since the daily living tasks module may not fully indicate the individual's level of disability and how it affects work-related tasks. Although we only analyzed the work module, both modules are scored the same way. Both are four questions and scored the same as the prior 30 questions, 1 to 5. All questions must be answered in this section to calculate a DASH score. These scores are calculated by adding the response values together and dividing by four (the number of questions answered). One is subtracted and then multiplied by 25. Again, the higher the score, the higher the disability of the individual.

The validity of the DASH has been proven to be accurate for a wide variety of individuals who self-reported pain or injury to the arm, shoulder and hand, including differences such as age, gender, education, location and injury type (Beaton et al., 2001). The DASH was able to differentiate between participants who could continue to work even with an upper extremity condition, those who were able to do all tasks they wanted versus those who were unable. In terms of reliability, test-retest indicated there were no statistically significant changes in responses, with a mean change in score of -0.15 (Beaton et al., 2001).

Another study performed by Rodrigues et al. (2015) used the DASH to focus on pre- and post-operative patients with Dupuytren's disease, a connective tissue disorder of the hand/wrist. The DASH did prove to be reliable for tracking pain, especially if taken before surgery, immediately after, and then in the following weeks to assess that pain levels are below or at the same level as before surgery. Rodrigues et al. did find that the Cronbach's alpha for the DASH was 0.975, indicating that it is not unidimensional despite one overall DASH score being created. Especially in patients with Dupuytren's disease, this could make it hard to interpret if there are comorbidities of the upper arm being assessed.

3.4.1.4. Foot and Ankle Ability Measure (FAAM). This questionnaire was used to determine the individual's foot/ankle function. Participants who indicated they suffered from a foot/ankle injury which restricted on-duty fire tasks were asked twenty-one questions about daily living activities. They then answered using a Likert-type scale of 0 (cannot perform task) to 4 (can perform task with no difficulty). If the patient is unable to do a task, not due to their foot/ankle injury, not applicable (N/A) is an optional choice. All questions must be answered to formulate a score. Scores will be calculated by totaling the individual participant scores, subtracting N/A answers from the individual total responses, and finally dividing the individual participant scores by the revised individual total responses. This quotient is then multiplied by four. The resulting number is multiplied by 100. The final number is the participant's percent physical function. The higher the score, the greater the function of the individual.

The FAAM has been shown to be both valid and reliable with research indicating that if conditions of the foot and ankle remain stable, overall scores remain stable as well in the re-test. Research conducted by Martin et al. (2005) divided a wide variety of participants (age, gender, injury type, and duration of injury) into two separate groups: one group that had been treated for the same injury one year prior and was anticipated to remain in the same condition despite physical therapy. The other one that was anticipated to improve with physical therapy. In the group anticipated to remain the same, average initial scores for the activities of daily living portion of the FAAM were 91.5, which is considered excellent. For the sports subscale scores were 78.6, which is considered slightly above average. On the retest (average of 65.6 days later), scores were relatively the same, 92.6 and 81.9, respectively. The closer the score is to 100, the more function the patient has. This outcome displays validity, with a test-retest method, showing no major changes in how participants responded.

Carcia et al. (2008) focused their research on athletes with chronic ankle instability (CAI) and the validity of the FAAM when assessing their overall disability. After dividing subjects into two groups (healthy and CAI), results from the FAAM were analyzed. Those who indicated their ankle was “normal” had higher scores on both the activities of daily living portion and the sports subscale. Those that reported that their ankle was “nearly normal” or “abnormal” had lower scores, indicating that they had less function. These results support the validity of the FAAM as a measure of overall ankle function.

3.4.1.5. Hip and Groin Outcome Score (HAGOS). This questionnaire focused on hip and groin disability. It is broken down into six different sections with each question focusing on general movement and pain patterns. Each question is answered by checking one box on a Likert-type scale that is appropriate to that particular question. The sections include pain, symptoms, stiffness, activities of daily living, sports/rec, physical activities (PA) and quality of life (QOL). Each section has a specific calculation depending on the number of questions in that section. The total score of the questions in a specific section is multiplied by 100. That value is then subtracted from 100, then divided by the highest possible score for that section. The lower the score, the more self-reported problems that individual has in that particular area with their hip/groin. These scores are often times charted on a line graph and used to visually represent pre- and post-treatment to track progress.

The HAGOS was developed specifically for young-to-middle-aged physically active patients with long-standing hip and groin self-reported pain. To test for validity, Thorborg et al. (2011) compared the HAGOS to the SF-36, a well-established physically active questionnaire, to compare for a possible correlation between the two questionnaires. All portions of the HAGOS were indicated to be highly correlated with the SF-36 (.04 for Spearman coefficient) except the quality of life section, which was a .38, slightly below the study's hypothesis threshold of .4. Test-retest reliability was also excellent, with intraclass correlation coefficient scores between 0.82 and 0.92. These results indicate that the HAGOS is a valid and reliable survey for individuals who are physically active with hip or groin pain. Other studies have agreed with these findings (Kemp et al., 2013).

Similar results regarding the validity and reliability of the HAGOS were reported by Thorborg et al., (2013) who conducted research on professional soccer players to establish whether the questionnaire was appropriate measure of hip and groin pain in this specific population. Of the 444 HAGOS questionnaires collected at the beginning of the season, 143 participants indicated they had experienced hip/groin pain in the last season but were healthy now. These 143 participants all had higher HAGOS baseline results than those who had not experienced any pain in the previous season, indicating that the HAGOS is useful in detecting and monitoring hip and groin pain in male soccer players, even during extended periods of time.

3.4.1.6. Knee Injury and Osteoarthritis Outcome Score (KOOS). This questionnaire is similar to the HAGOS in that it uses the same six sections and general scoring calculations.

However, the KOOS focuses on the knee rather than the hip/groin region. The questions are answered by checking the appropriate response for their particular pain or mobility level. The calculation is slightly different from the HAGOS questionnaire. Each section has its own score, but it is calculated by multiplying the raw score by 100. That number is then divided by 100 minus the highest possible raw score range for that section. The closer to 100 the individuals' report is, the fewer problems the individual has.

Roos et al. (1998) tested the validity and reliability of the KOOS with positive results in patients with ACL and meniscus injuries. To analyze validity, the 36-item short-form health survey (SF-36), a widely used and tested survey, was used as the "gold standard" for the activity subcategories. It was administered to participants when the KOOS was administered for comparison. Using kappa statistics, scores were high, sitting between 0.46 and 0.57. In regard to test-retest reliability, correlation coefficients ranged from .75 to .93, which all fell into the "highly correlated" category defined by the study. These results from the KOOS when compared to the SF-36 indicate that the KOOS is both valid and reliable when analyzing the disability of knee injury patients.

In regards to using the KOOS to monitor patients after an ACL reconstruction, it has been demonstrated that it is both valid and reliable (Salavati et al., 2011). Comparing the KOOS to the SF-36, the validity was very good with Spearman's correlation coefficients falling between 0.72 and 0.79, which is considered strong. The reliability aspect of then KOOS was also high, with all ICC values above the 0.70 acceptable level, ranging from 0.74 to 0.96. These results indicate that the KOOS can be used to monitor progress in post-surgical ACL patients.

3.4.1.7. Lower Extremity Functional Scale (LEFS). This questionnaire analyzes more general lower extremity issues, rather than focusing on just one specific joint. Twenty questions were asked regarding the patient's condition at that moment and if they could perform a certain task. Each question is scored from 0 (extreme difficulty/unable to perform activity) to 4 (no difficulty). The raw score from each question is totaled out of 80 total points. The closer to 80 the individuals score is, the fewer problems they are having.

Similar to previous questionnaires listed, the SF-36 was used as a comparison when researchers were testing validity and reliability. Validity of the LEFS was tested by Binkley et al. (1999) using Pearson correlations, while test-retest reliability used confidence intervals. Validity scores were between .64 and .80, indicating it is of sound testing. The test-retest reliability confidence intervals were .80 when compared to the SF-36. These scores indicate it to be a reliable questionnaire for lower extremity injuries.

When surveying a population of orthopedic inpatients, the reliability and validity of the LEFS proved to be good (Yeung et al., 2009). The ICC was 0.88, which shows that it is appropriate for this population of people with much more significant injuries requiring more intense rehabilitation. The validity was only partially supported in this study, but researchers did mention that they believe the comparison instruments used measured different attributes resulting in the lower correlation scores.

3.4.1.8. Neck Disability Index (NDI). Considering the spine at the cervical level only, the NDI is divided into 10 sections focusing on different aspects of daily life. These sections include: pain intensity, personal care, lifting, work, headaches, concentration, sleeping, driving, reading, and recreation. Each section offers six choices, ranging from "least severe/not at all" to "most severe/always", and is scored 0 to 5 respectively. All of the sections are added together and totaled out of 50 points. The farther the individuals' score is from 50, the fewer problems the individual self-reports.

Cleland et al. (2012) found that using the NDI with cervical radiculopathy patients may not be the best choice when compared to other measures (such as the Patient Specific Functional Scale or Numerical Pain Rating Scale), but still yields both valid and reliable results. Comparing two groups of patients (one expected to remain the same during physical therapy and one expected to improve), researchers examined their responses at the beginning of therapy and then a follow-up an average of 21 days later. The results indicate that the group which was expected to remain stable had an ICC value of 0.68, which is acceptable, but not as high as the ICC value for the Patient Specific Functional Scale (PSFS), which was 0.82. Although not as qualified for this specific condition, the researchers noted that it is valid and reliable for patients with general neck pain. Other studies have found similar positive results when compared to other neck specific questionnaires (Hung et al., 2015. Schellingerhout et al., 2012), the Oswestry low back pain questionnaire (Pereira et al., 2017), and the physical aspects of the SF-36 (Juul et al., 2016).

3.4.1.9. Oswestry Low Back Pain Disability Questionnaire. Focusing on the low back spinal column, this questionnaire is divided into 10 sections of daily life activities: pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling. Similar to the neck disability index, each section offers six choices ranging from "no pain/not affected by pain" to "extreme pain/cannot participate due to pain" and is scored 0 to 5 respectively. To calculate a score, the raw score from each section is added together, then divided by 50 (total possible score). That number is multiplied by 100 to give a percentage of disability. If one section is missing, the score can still be calculated by using 45 for the total possible score instead. Zero to twenty percent is considered minimal disability, 21-40% is considered moderate, 41-60% severe, 61-80% crippled, and 81-100% either bed-bound or exaggerating symptoms.

The Oswestry Low Back Pain Disability Questionnaire was created to measure the level of disability for acute and chronic back pain in patients who have used conservative and surgical options. The reliability of this test has a Cronbach's alpha value of .71 to .87, and a correlation score between .91 and .83, indicating that it is of sound reliability. The validity of this test was analyzed against a visual analogue scale with a correlation coefficient of .62 (Fairbanks et al., 2000). Similar studies found the same results that the Oswestry has high validity and reliability (Cleland et al., 2012. Fairbank & Pynsent, 2000. Ramas et al., 2017. Saltychev et al., 2017).

Like many of the studies listed above, Hashimoto et al. (2006) used the SF-36 as a comparison when analyzing responses from Japanese outpatients with lumbar conditions. They found that Cronbach's alpha was 0.94, and that the Pearson's correlation coefficient ranged from .80 to .61, being least correlated with the mental health questions of the SF-36. These results show that this questionnaire is indeed valid and reliable in this patient population of general back pain, but due to its lack of mental health questions, it is poorly correlated with other measures that focus more on mental health. Taylor et al. (1999) also agreed with these findings.

3.4.2. Equipment

3.4.2.1. Resusci Anne® QCPR Manikin. Resusci Anne® QCPR Manikin (Laerdal Medical AS, Stavanger, Norway) includes a manikin and feedback software which can assess chest compression rate, depth, hand placement, chest recoil, and ventilations (Thoren et al., 2006). Using the feedback software, these raw data points were analyzed and used to calculate chest compression ratio, percent correct for each component of CPR, and give an overall CPR score. These scores were saved for each rescuer and used later to determine relationships between injuries and cardiorespiratory fitness.

Existing research using the medium-fidelity equipment has been cited in articles as an accurate way to measure CPR performance. In 2014, Laerdal Medical made improvements to the older version of the Resusci Anne® QCPR. Thus, the existing research which has incorporated the Resusci Anne® QCPR as a part of the research project has reported results from the older equipment. The manikin has been used in studies aimed to improve CPR quality, ranging from testing automated chest compression devices (Szarpak et al., 2016), pre-hospital CPR quality (Higdon et al., 2006; Liberman et al., 1999) in-hospital CPR (Ashton et al., 2002; Noordergraaf et al., 2006; Thoren et al., 2006), and most commonly researched, rescuer fatigue (Ashton et al., 2002; Hasegawa et al., 2014; Ochoa et al., 1998; Yang et al., 2014). Researchers have used this manikin and software because it is easy to use and similar to performing real CPR. More advanced models can be purchased which can simulate pulses, respirations, and other emergency scenarios to create an even more realistic scenario. The Resusci Anne® QCPR manikin is essential to capture all aspects of a participant's CPR performance and provide feedback to assist with deliberate feedback practice.

3.5. Statistical Analysis

All statistical analyses were conducted using SPSS (version 24). Statistical significance was at the 0.05 level of confidence. The following analyses were used to answer the research questions:

1. Is there a statistically significant correlation between prior orthopedic injuries sustained by firefighters and their ability to perform effective CPR?
    a. A Spearman's correlation coefficient with the level of agreement between the subjectively reported data on surveys and the objective data reported by the Resusci Anne® QCPR.

2. Does performing a VO_{2max} protocol influence prior orthopedic injuries and a firefighter's ability to perform effective CPR?

   a. The quality of CPR was analyzed with a series of paired t-tests (pre- and post-graded exercise test). Due to the large number of comparisons, p-values were adjusted using a Bonferroni correction.

3.6. Conclusion

In summary, there is minimal research investigating the relationship between musculoskeletal injuries and an individual's ability to perform high-quality CPR. Further, no published research exists which explores the relationship between prior injuries in firefighters, who are often the first responders to a cardiac event. It has been established that CPR is a labor-intensive task even if performed correctly (Ashton et al., 2002; Ochoa et al., 1998; Scapigliati et al., 2010; Shultz et al., 1994). The job-specific skills performed by occupational workers (i.e., firefighters and policemen) are now being compared to professional athletes. Therefore, studying the impact of musculoskeletal injury to job performance is critical for the well-being of the general public as well as return-to-work considerations for firefighters. The proposed research project analyzed CPR considerations for firefighters through musculoskeletal questionnaires, medium-fidelity equipment, and VO_{2max} data. The results of the project provided the opportunity to consider changes in policies for firefighters in addition to the panel of experts who make critical changes to the cardiopulmonary resuscitation protocols.

CHAPTER 4. MANUSCRIPT

4.1. Abstract

Firefighters' on-duty tasks require a great deal of physical activity, with one of the more labor-intensive tasks being critical medical intervention: cardiopulmonary resuscitation (CPR). Quality CPR is an essential component in cardiac arrest survival. Research indicates a first responder's performance may become inadequate due to many factors including fatigue or distractions, but the impact of prior musculoskeletal injuries has not been studied. The purpose of this study was to determine if a correlation exists between a firefighter's CPR performance, fatigue, and prior musculoskeletal injuries. Twenty-nine urban firefighters (34.45±7.15 years) participated in the present study and supplied researchers with basic demographics and a self-reported musculoskeletal injury history through secondary injury questionnaires. In order to investigate the effects of fatigue on overall performance of CPR, firefighters performed five rounds of single-rescuer CPR, participated in a graded exercise test (GXT) until they reached volitional fatigue, followed by a second set of five rounds of CPR. Results indicated BMI was a predictor for overall CPR score pre-GXT. BMI and back pain were indicators for full chest recoil pre-GXT. This study suggests that BMI and the presence of back pain may have an impact on CPR performance quality in firefighters.

4.2. Introduction

Out-of-hospital cardiac arrest (OHCA) has been reported to affect nearly 350,000 individuals in the United States (AHA, 2016). Studies have found the sooner a victim of cardiac arrest can receive cardiopulmonary resuscitation (CPR), the more likely they are to survive the incident (DeRuyter et al., 2017; Hoyer & Christensen, 2009; Nolan, 2014; Saner et al., 2013; Yang et al., 2014). Over a five-year period, researchers in Seattle, Washington recorded a total of

2,485 incidences of cardiac arrest. The inclusion criteria for this specific study involved cardiac arrest occurring before firefighters arrived on scene along with sufficient data to be time-stamped. Based on the chosen methodology, 1,806 cases of cardiac arrest were used for statistical analysis. Results indicated there was a strong and inverse relationship between patient survival and each additional minute firefighters were delayed. Even with a mean "9-1-1 activation to hands-on EMS care" (DeRuyter, 2017, p. 52) time interval of 7.2 ± 3.6 minutes, only 19% of victims survived, supporting the necessity of immediate care performed by trained rescuers to increase survival chances. Another component to increasing survival rates, in addition to immediate initiation of CPR, is the quality of CPR delivered. Studied factors that can be attributed to poor performance and subsequently decrease the chance of survival include improper technique (Nolan, 2014; Wik, 2005), distractions (Kim et al., 2015; Thoren et al., 2001), and poor training (Fernandez et al., 2015).

One component potentially related to inadequate execution of CPR skills that has received little or no attention is the role of previous or current musculoskeletal injury in the first responder. Rather, most of the research has focused on generally healthy firefighters (Geddes et al., 2001; Liberman et al., 1999) and other medically trained professionals. These studies have indicated many of the individual components of CPR are performed ineffectively (Ashton, 2002; Noordergraaf et al., 2006; Ochoa et al., 1998. Thoren et al., 2001). Geddes et al (2001) stated the force needed to compress the chest 1.5 to 2 inches was 100 to 125 pounds of force, respectively. Of the 83 firefighters studied, only 60% could produce 125 pounds of force. An important note to this study is that the parameters followed the 2000 AHA Guidelines for chest compression depth; these parameters called for 1.5 to 2.0 inches of compression for an adult patient. The 2015 Guidelines state a rescuer should compress the chest 2 to 2.4 inches, which would require 125 pounds of force or more to achieve. The updated guidelines now require Basic Life Support trained individuals to increase high force output, which could potentially exacerbate pre-existing pain or cause injury while performing the medical intervention.

Injury rates in firefighters have been reported to be approximately seven times higher when compared to other workforce jobs (Leffer & Grizzell, 2010). Knowing that injuries take time to heal, it could be assumed firefighters' work performance is less than optimal during their recovery period. Researchers analyzing firefighter injuries concentrate on active-duty injuries and fatalities focusing primarily on the breakdown of fireground injuries (Fahy, LeBlanc & Molis, 2015. Haynes & Molis, 2014). In 2014, 27,015 injuries were documented among United States firefighters, with 52.6% and 59.4% classified as strains, sprains, and muscular pains that occurred during fireground and non-fireground operations, respectively (Haynes & Molis, 2014). While there is little available published research investigating musculoskeletal injuries in firefighters, a comparison can be made to EMTs since the job demands are similar when responding to medical calls. Studnek et al. (2010) analyzed survey responses from EMS workers who self-reported back pain. About half (50.5%) reported pain in their back at least once in the previous two weeks. It was not specified if pain was attributed to work-related tasks, but it did note 65.8% of responders with back pain were classified as overweight or obese.

Musculoskeletal injuries can also occur during non-working hours, which does not make the injury eligible as a workman's compensation claim. Because these injuries are not covered financially from the employer, they may not be diagnosed or treated properly. A firefighter may try to continue to work despite not being able to perform all work-related tasks to their fullest ability. If an individual cannot work, they may be taken off active duty, thus losing income. Although Scuderi et al. (2005) did not analyze firefighters specifically, researchers found that patients who had to cover the cost of care for whiplash treatment following a motor vehicle accident were more likely to return to work sooner than those whose injury fell under workman's compensation. This idea supports the notion that due to financial burden, firefighters may be more likely to return to work before they are ready. This not only affects a firefighter's job-related skills, but also creates a public safety issue if they are unable to perform skills related to CPR.

Although no relationship could be found between previous musculoskeletal injuries affecting CPR performance, there is literature that has determined the act of performing CPR may cause injuries, specifically back injuries. One researcher performed two separate studies regarding injuries sustained during CPR; one study that investigated nurses and the other that recruited EMTs. The studies found similar results between the two groups with CPR performed by these professionals lasting nearly thirty minutes. Due to the length of time spent performing a physically demanding medical intervention, it can be hypothesized the medical professional has been placed in a compromised position thus predisposing them to musculoskeletal injury. Nearly all instances involving the delivery of chest compressions occurred on a hospital or at-home bed. (Jones, 2004; Jones & Lee, 2005), which could influence biomechanical alterations thus potentiating injuries. Additionally, the movement of the ambulance or turning of the head to read the ECG monitor increases the chance of injury. Eighty percent of nurses and 96% of EMTs complained of back discomfort while performing CPR and approximately half of both groups considered this improper positioning as the cause of their back injuries (Jones, 2004; Jones & Lee, 2005). Although the researchers did not specifically target firefighters' CPR performance, nurses and EMTs participate in a similar line of work, as they are expected to perform CPR for extended periods of time in unconventional environments. Because performing CPR is a physically demanding task, firefighters with predisposing conditions could potentially increase their risk of sustaining injuries.

High-quality CPR is critical for the best possible outcome when responding to more than 300,000 cardiac incidences in a given year. Previous research suggests performing CPR can cause injury. However, no researchers have conducted a prospective methodology to consider the role of prior musculoskeletal injury to injuries sustained while performing job-related tasks. Thus, the purpose of this research was to analyze the effects of volitional fatigue and prior musculoskeletal injury to firefighters' CPR performance.

4.3. Materials and Methods

4.3.1. Subjects

This study was approved by the research team's Institutional Review Board before any recruitment or testing was initiated. Twenty-nine male career firefighters (34.45±7.15 years) from the same Midwestern urban fire department volunteered for this study. Participants were recruited by attending informational meetings or by word-of-mouth recruitment. Each participant had to be an active-duty firefighter between 20 and 55 years of age. Participants were excluded if they were unable to perform active-duty tasks due to a current injury or medical condition. Volunteers for this study were dismissed if they were unable to perform treadmill walking with department-issued turnout gear, or there was previous medical concern from prior graded exercise tests (GXT).

4.3.2. Research Design

A repeated measures design was used to observe the effects of both injuries and fatigue on the CPR performance of firefighters. After completion of the required demographic paperwork, participants' height and weight were taken before and after putting on their turnout boots and pants. They were given a heart rate monitor (Polar Electro Inc., Lake Success, NY, USA) and fitted for a mouth piece for the Parvo metabolic cart (Parvomedics, Logan, UT, USA) to be used during both CPR and the exercise protocol. Each subject performed five rounds of CPR on a Resusci Anne® QCPR manikin (Laerdal Medical AS, Stavanger, Norway), completed the designated VO_{2max} protocol, then completed five more rounds of CPR.

4.3.3. Questionnaires

Prior to exertional testing, all subjects were provided with an informed consent to read and sign, a basic demographic survey, and the Extended Nordic Musculoskeletal Questionnaire (NMQ-E). The NMQ-E was utilized as an initial injury screening survey to determine if any past or current injuries met the requirements for an additional survey. Of the total responses, 25 of the reported injuries were deemed significant to elicit the need for additional, body-part specific questionnaires, which served to investigate specifics about the previous or current injury. A significant injury was determined by how recent their pain was and if the reported injury had forced them to change jobs duties or take time away from work. The additional surveys selected for the current research included the Neck Disability Index (NDI), the Disabilities of the Arm, Shoulder and Hand questionnaire (DASH) with the work sub score, the Oswestry low back Disability Index (ODI), the Hip And Groin Outcome Score (HAGOS), the Knee Injury and Osteoarthritis Outcome Score (KOOS), and the Foot and Ankle Ability Measure (FAAM). For our research purposes, CPR components were analyzed between the “injured” group (n=21) and the “non-injured” group (n=8). Follow-up statistical analysis extrapolated only those firefighters who completed the ODI based on few reported injuries for other areas of the body.

4.3.4. CPR

Using the Resusci Anne® QCPR manikin, each participant was asked to perform five rounds of CPR consisting of 30 compressions and two rescue breaths. For the purpose of this study, the research team focused on the participants' performance of overall chest compression score, number of compressions performed, mean depth of compressions, percentage of chest compressions that achieved full recoil, and mean chest compression rate both before and after the exercise protocol. Although these participants were asked to perform ventilations using a bag valve mask, the results were not analyzed since the likelihood of a firefighter performing both chest compressions and bag valve mask ventilations is unlikely since additional firefighters would be present to perform two-rescuer CPR.

4.3.5. GXT

This study used the Balke-Ware GXT (Balke & Ware, 1959) to assess VO_{2max} as well as exhaust firefighters in order to simulate job-specific demands. During this protocol, data were collected using a metabolic analyzer, heart rate monitor, and a Trackmaster TMX425C treadmill (Full Vision, Inc., Newton, KS). Participants were asked to wear their turnout pants and boots while performing the GXT. This, along with the walking-only GXT, simulated fireground activities, which created a more realistic setting in which to collect data. After a brief, three-minute warm-up period, participants began the protocol, which initially consisted of a 3.3 MPH pace and 0% gradient. After the first minute, the gradient was increased to 2% then increased by 1% every minute thereafter. Once the participant reached volitional fatigue, the treadmill was lowered to the gradient in which the participant had met roughly 50% of their VO_{2max} for a three-minute active recovery period. Finally, the treadmill was raised to the gradient that was two stages below the participant's last stage attained before fatigue. There was no time limit associated with the last portion of the protocol since it was used only to verify the VO_{2max} was achieved previously, and participants were instructed to walk until they felt that same level of fatigue as before.

4.3.6. Statistical Analysis

All statistical analysis was conducted using SPSS. Thirteen separate independent sample t-tests were used to analyze the differences between the “injured” and “non-injured” group on the dependent variables. Four multiple hierarchical regressions were used to analyze whether or not BMI and/or the presence of a back injury predicted pre- and post- VO_{2max} rate of compression as well as VO_{2max} chest recoil percentage. Four separate hierarchical regression were run with the first block containing BMI and the second block containing the variable indicating the presence of a back injury. The regressions only varied in terms of the dependent variable. An alpha level of .05 or less was considered statistically significant for all comparisons.

4.4. Results

Table 1 lists the demographic information for the 29 participants who volunteered for this study. The included age range was 20-55, and only males were used due to the fact that this particular department had only men on active duty. Age was not a statistical factor in the calculations for this study.

Table 1

Participant Demographics

	Age (years)	Height (cm)	Weight (kg)	BMI	VO_{2max}
Males	34.45±7.15	180.74±5.70	94.32±10.91	28.90±2.41	40.8±6.9

Table 2 lists the six secondary surveys included, along with the number of participants who completed each one. Some participants filled out multiple surveys resulting in the total number of completed surveys being only slightly smaller than the total number of participants. The ODI had significantly more completed surveys, almost two times as many as the next highest (NDI and DASH).

Table 2

Surveys and Responses

Name of survey	N
NDI	4
DASH	4
ODI	13
HAGOS	1
KOOS	2
FAAM	3
Total	25

In terms of statistical results, the independent samples demonstrated no statistically significant differences between injured and non-injured participants on the dependent variables. ($p>0.05$). It is worth noting (overall)75.24+19.28= injured 84.5+10.11= non-injured.

Several linear regressions were run to investigate if BMI and/or back injury predicted different compression components of CPR. Table 3 summarizes the block linear regression with overall CPR score for pre-GXT as the dependent variable and BMI and back injury as the independent variables (R2=0.15). BMI was predictive of overall CPR score pre-GXT (F (1,27) =9.92, R2=0.15, p=0.35). Additionally, both BMI and back injury were predictors of percent of full chest recoil for compressions pre-GXT (F (1,27) =4.55, R2=0.27, p=0.018) (Table 4).

Table 3

Summary of Hierarchical Regression Analysis for Variables Predicting Overall CPR score Pretest

Variable	*B*	*SE B*	*β*
Step 1			
Constant	157.09	35.90	
BMI	-2.74	1.23	-0.39*
Step 2			
Constant	160.75	35.96	
BMI	-2.76	1.23	-0.40*
Presence of a Back Injury	-6.57	6.13	-0.19

Note: R^2 = .39 for Step 1; R^2 = .44 for Step 2. * $p < .05$ ** $p < .01$

Table 4

Summary of Hierarchical Regression Analysis for Variables Predicting Recoil Pretest

Variable	*B*	*SE B*	*β*
Step 1			
Constant	233.03	52.17	
BMI	-5.20	1.79	-0.49**
Step 2			
Constant	238.11	52.36	
BMI	-5.24	1.79	-0.49**
Presence of a Back Injury	-9.13	8.92	-0.17

Note: R^2 = .49 for Step 1; R^2 = .52 for Step 2. * $p < .05$ ** $p < .01$

There were no significant differences for firefighters with back injuries and compression depth pre- (p>0.05) and post-GXT (p>0.05). Similarly, there were no differences in compression rate pre- (p>0.05) and post-GXT (p>0.05).

4.5. Discussion

The purpose of this research was to analyze the effects of volitional fatigue and prior musculoskeletal injury on firefighters' ability to perform cardiopulmonary resuscitation (CPR).

The methodology employed in this original research tested the ability of firefighters to complete the Balke-Ware Treadmill test. The VO_{2max} protocol requires individuals to walk on a treadmill at 3.0 mph while raising the incline of the treadmill by 1% every minute. Typical VO_{2max} procedures necessitate running as the mode of exercise. However, the researchers were investigating job-specific demands of firefighters; therefore, a protocol designed to simulate the job duties of a firefighter were included. The average VO_{2max} of the 29 firefighters was 40.8±6.9 ml/kg/min. Although the current recommendation by the National Fire Protection Agency (NFPA) is for firefighters to obtain a VO_{2max} of 42 ml/kg/min, there is little research to suggest this number is valid for career firefighters. It should be noted, however, that several of the participants were well below the recommendation by the NFPA as well as the American College of Sports Medicine for their age classification. Thus, further studies are needed to compare several job duties as well as type of employment (i.e., career versus volunteer versus wildland).

Additional results indicate BMI was predictive of overall CPR score pre-GXT; BMI was also predictive of percent of full chest recoil pre-GXT. Sayee & McCluskey (2011) reported first year doctors with a BMI greater than 24 performed better CPR than their counterparts with a BMI lower than 24. In the general population, a higher BMI is often associated with obesity since BMI only considers height and weight but does not differentiate between muscle mass and body fat (Burkhauser & Cawley, 2016). There is conflicting research about the causes of firefighters' commonly high BMI compared to the general population. Some researchers argue firefighters engage in physically demanding tasks as part of their daily work routine and require a higher muscle mass to be able to perform these tasks (Choi et al., 2016, Jitnarin et al., 2013). Others argue the obesity epidemic does not exclude firefighters despite their physically demanding jobs (Gurevich et al., 2016; Poston et al., 2014). Regardless of the reason as to what causes the increased BMI in firefighters, the research generally agrees a higher BMI can enhance performance of high-quality CPR (Hasegawa et al., 2014; Lin et al., 2016; Oh & Kim, 2016; Sayee & McCluskey, 2012).

Although we found statistical significance for the relationship between pre-GXT CPR scores and BMI, no correlation was found between post-GXT CPR and BMI. There are studies that indicate exhaustion decreases CPR performance (Aufderheide et al., 2005; Ochoa et al., 1998; Yang et al., 2014), which contradicts the current study's results. One study found that not only did rescuers performing CPR not realize when their performance was diminishing due to fatigue, but within two minutes of starting CPR, performance decreased 54.8% (Ochoa et al., 1998). The first minute of CPR performance had a high mean percentage of correct compressions at 79.7%, however this rate decreased per minute to 24.9% (minute 2), 18% (minute 3), 17.7% (minute 4), and 18.5% (minute 5) following the initial minute of compressions. Based on the research by Ochoa et al. (1998), we hypothesized those firefighters with a higher BMI would perform better following exhaustive exercise. Thus, the conflicting results in the current study necessitate future research regarding fatigue and BMI.

Another important result of this study was the poor full chest recoil performance in firefighters. Chest recoil is defined as "the return of the sternum to its natural position during the decompression phase of CPR" (AHA Guidelines, 2015, p. 9). Incomplete chest recoil would involve leaning on the chest wall. This position does not allow the heart to fully refill with blood resulting in less blood available to be pumped throughout the body. Aufderheide et al. (2005) observed resuscitative efforts on victims by healthy EMS personnel and noted at least 46% of chest recoil was incomplete. The same EMS personnel performed CPR on manikins, and the software used reported only 16.3% of chest recoil was considered full. The results of this study indicate healthy rescuers struggle to achieve full chest recoil in both live and simulated environments. An inference can be made that any pre-existing back injury could result in using alternative muscles to conduct CPR thereby causing the firefighter to lean on a patient's chest cavity.

Due to the low secondary injury survey responses in the current study, researchers could only focus statistical efforts on the results of one survey. Potentially due to the exclusion criteria established by the researchers, the firefighters participating in the study were currently active and reported few musculoskeletal injuries. The survey with the highest response rate was the Oswestry Disability Index for low back pain. A total of 13 individuals indicated on the NMQ-E they suffered from some type of low back pain or injury. The results of the follow-up ODI resulted in very low scores indicating minimal to low disability due to back pain. Upon further investigation, the research team concluded the ODI focused mostly on general life tasks, such as personal hygiene and social factors. Although these components are important, the focus of this study was on a specific job-related task, CPR. One low back survey that could have had better alignment with the researchers' focus is the Quebec Back Pain Disability Scale (Kopec et al., 1996). This survey contains 20 questions and includes tasks like "climb one flight of stairs," "walk a few blocks," "reach up to high shelves," and "push or pull heavy doors." These tasks are more applicable to a firefighters' work demands and give more specific choices to the actions and tasks, which potentially exacerbate back pain.

There were some limitations associated with the methodology. One of the limitations was the low response rates to the secondary injury surveys. Although we had a total of 25 injury surveys completed, the number of completed surveys per body part was dispersed rather unevenly. Outside of the ODI, the surveys with the next highest response rate were the NDI (n=

4) and the DASH (n= 4). Although these responses are valuable to research, they do not have statistical power to be compared to other injuries or firefighters who did not report an injury. The other methodological concern with the secondary surveys was that many of the scores indicated a low level of disability or no disability at all. The current study used the NMQ-E as an initial screening tool, which firefighters often reported pain in a certain body region. However, when completing the area-specific questionnaire, the firefighters often reported insignificant pain or injury. Therefore, differentiating CPR scores between poor performance due to pain or injury and simply poor performance due to other factors was impossible.

Because the idea of injuries affecting CPR performance is understudied, the current study may create future research ideas that have the potential to understand this relationship more intimately. Analysis of rehabilitation protocol's effects on first responders' performances before and after injuries could benefit individual firefighters and their departments, as well as the general public. The real-world impact of such a study could also help advocate for a "return to play" protocol for firefighters attempting to return to active duty. The results of this study suggest there is a link between BMI and overall CPR performance before an exhaustive bout of exercise, as well as BMI and low back pain being predictive of chest recoil before an exercise protocol. Being better able to understand, recognize, and comprehend how health factors affect CPR performance can help researchers also learn how to improve CPR performance and improve survival rates in the community.

4.6. Conclusions

With survival of a cardiac event relying on quick intervention and quality CPR performance, first responders, such as firefighters, should be in good physical health to ensure they are able to conduct high-quality medical interventions. As described in previous literature, many factors can influence CPR performance. However, no researchers have conducted original research investigating the role of previous musculoskeletal injury in firefighters and their ability to perform high-quality CPR. The results of this study suggest there is evidence BMI is predictive of pre-GXT CPR performance, and both BMI and back injury are predictors of percent of full chest recoil for compressions pre-GXT. Overall, the link between injuries and CPR performance needs more research to better understand how to improve CPR performance and increase survival rates.

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