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Richard Scott Dainty
dain5450@mylaurier.ca

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Investigation of low back and shoulder demand during cardiopulmonary resuscitation: the effect of different compression-ventilation ratios

Richard Scott Dainty

Supervisor: Dr. Diane Gregory

Submitted to the Department of Kinesiology and Physical Education,

In fulfillment of the requirements for the Masters of Science in Kinesiology

Wilfrid Laurier University

Abstract

Background: The current American Heart Association (AHA) standard cardiopulmonary resuscitation (CPR) is performed with a compression-ventilation ratio of 30:2 (standard CPR), meaning 30 compressions are applied to the chest followed by the administration of two breaths to the victim. Some evidence has shown that performing continuous chest compressions rather than standard CPR with breaks in chest compressions for administering breaths, may increase survival rates after cardiac arrest. Cont-CPR has been shown to be very fatiguing in nature, with a significant drop in chest compression force within the first two minutes of CPR. The purpose of this study was to examine and compare the biomechanical demand of individuals performing cont-CPR and standard CPR under timing conditions that are representative of a three-person rescue team.

Methodology: Fifteen individuals (ten emergency responders, five civilians) performed two sets of CPR trials; one set was performed using standard CPR (30:2) and the other set using cont-CPR. The order in which these CPR types were presented to each participant was randomized. The first set of trials comprised of three two-minute periods of CPR administration, during which the chest compressions were performed on a force transducer that was placed over the sternum of a CPR mannequin. In between each two-minute trial, the participants were given four minutes of rest (to simulate a three-person rescue team). After the third CPR trial, the participants were given 30 minutes of rest before repeating the complete procedure performing the second type of CPR. Immediately prior to, and immediately after, completing each set of CPR trials (standard and cont-CPR), participants were instructed to fill out ratings of perceived exertion and discomfort scales (RPE and RPD, respectively) as well as perform a static back extensor test to evaluate low back muscular fatigue. During the CPR trials, the following measures were collected: 1)

Electromyography (EMG) data collected from four trunk muscles and two upper extremity muscles; 2) low back flexion using electromagnetic motion sensors; and, 3) chest compression force using a force transducer placed on the sternum of a CPR mannequin.

Results and Discussion: Chest compression force decreased significantly over the two minute standard and cont-CPR trials evident by a significant main effect of time ($p<0.0001$). There was also a significant interaction between CPR type and time ($p=0.011$) with regards to chest compression force. During the cont-CPR trials, chest compression force began to decrease immediately, whereas during the standard CPR trials, chest compression force was maintained relatively constant for the first 40 seconds, and subsequently began to decrease at a similar rate to the cont-CPR condition. Therefore, the overall drop in chest compression force was larger for the cont-CPR trials compared to the standard CPR trials. The amount of chest compression force varied greatly between the emergency responders and the civilians such that the majority of emergency responders were able to perform effective chest compressions (i.e. reach a level of chest compression force shown to be high enough to create blood flow) and many exceeded the maximum recommended chest compression force, regardless of CPR type. Contrary, most civilians were not able to sustain enough chest compression force throughout the two minute trials to maintain effective chest compressions. This has implications in both groups of individuals (emergency responders and civilians) as too much chest compression force may cause emergency responders to fatigue quickly and not be able to perform effective compressions, while too low of chest compression force may not effectively circulate blood in the victim’s body.

Significant increases in left and right lumbar erector spinae (LES) muscle activation over the two minutes of CPR, regardless of the type of CPR, were also observed in the current study ($p=.025$ and $p=.040$, respectively). These increases may be due to increased demand to maintain a

flexed posture during the performance of CPR. It is not likely that the increased amplitude of activation in the erector spinae muscles was due to fatigue as a decrease in the median power frequency was not observed following the CPR trials for either left or right LES (p=.412 and p=.549, respectively).

In the upper extremity, a shift in muscle activation was observed from the triceps brachii (TB) to the pectoralis major (PM). Specifically, a decrease in activation of the left TB (p=.022) was observed over time with a subsequent increase in activation of the left PM (p=.002). This finding suggests that the PM may have compensated for decreased force output from the TB likely as a result of fatigue. No differences in lumbar spine flexion were observed over time (p=.685) or between CPR conditions (p=.477).

Last, a significant increase in all the RPD variables and RPE scores was observed regardless of CPR type, which emphasized the exhausting nature of performing CPR.

Conclusion: The results of this study demonstrated that the performance of CPR over two minute bouts is fatiguing, regardless of CPR type. However, performing cont-CPR displayed an immediate and greater drop in chest compression force compared to standard CPR. This result may indicate a psychophysical aspect of performing cont-CPR compared to standard CPR. The very high chest compression force production from the emergency responders, along with the low chest compression force from the civilians, both pose their own problems that need to be addressed. If the AHA CPR guidelines are amended to perform cont-CPR rather than the current standard CPR, it is suggested that during a multi-person rescue, the duration of CPR administration should be shortened to less than two minutes; ideally one or one and a half minutes for each rescuer rotation to help prevent fatigue.

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List of Abbreviations

AHA	American Heart Association
ANOVA	analysis of variance
CDC	Center for Disease Control
Cont-CPR	continuous chest compression cardiopulmonary resuscitation
CPR	cardiopulmonary resuscitation
EMG	electromyography
EMS	emergency medical services
EO	external oblique
FFT	fast fourier transform
LBP	low back pain
LES	lumbar erector spinae
MdPF	median power frequency
MVC	maximum voluntary contraction
NFPA	National Fire Protection Association
NIRS	near infrared spectroscopy
OHCA	out-of-hospital cardiac arrest
PM	pectoralis major
RA	rectus abdominus
ROC	resuscitation outcomes consortium
ROM	range of motion
RPD	rating of perceived discomfort
RPE	rating of perceived exertion
TB	triceps brachii
TES	thoracic erector spinae

1.0 Introduction

The performance of cardiopulmonary resuscitation (CPR) particularly with respect to compression-ventilation ratio, has been investigated greatly (Cavus et al., 2008; Chandra et al., 1994; Hupfl et al., 2010; Iyanaga, et al., 2012; Kern, Hilwig, Berg, Sanders, & Ewy, 2002; Trowbridge et al., 2009; Valenzuela et al., 2005). Such investigations stem from the notion that an increase in survival rate after cardiac arrest may exist if CPR is performed using continuous chest compressions (cont-CPR) rather than the current American Heart Association (AHA) standard CPR, which uses a compression-ventilation ratio of 30:2. The AHA sets CPR guidelines and amends them as new research on procedures and technologies is conducted, where outcomes regarding victim survival may be improved. Prior to 2010, CPR was performed by first determining if the airway was clear or obstructed, then checking whether the victim was breathing, followed by the administration of chest compressions. This order is known as ABC (airway, breathing, compression). In 2010, the main amendment with regards to performing CPR switched from ABC to CAB such that the emphasis was placed on performing chest compressions first and foremost, acknowledging the importance of blood flow when trying to increase the chance of survival from cardiac arrest. Although most studies may not directly result in a change in procedure, they give insight into possible changes to CPR administration. For example, there have been investigations into the use of different compression-ventilation ratios during CPR, and the effect on individual's performance of the procedure (Geddes, Boland, Taleyarkhan, & Vitter, 2007; Jones & Lee, 2008; Trowbridge et al., 2009). With regards to compression-ventilation ratio, the current guidelines direct emergency responders to perform 30 chest compressions first, followed by two rescue breaths (30:2 CPR or standard CPR), repeating this as many times as needed until the victim becomes conscious or an automated external defibrillator becomes available. On the other hand, civilians are simply recommended to perform CPR faster and harder. The most recent investigations into possible CPR procedure amendments have looked into the performance of cont-CPR rather than the traditional 30:2 CPR as it has been suggested that cont-CPR may increase survival after cardiac arrest (Bobrow et al., 2010; Hupfl et al., 2010; Kern et al., 2002; Rea et al., 2010; Svensson et al, 2010; Zuercher et al., 2010). Cont-CPR is also known as 10:1 CPR, as represented by the compression-ventilation ratio. The main difference between standard and cont-CPR in terms of performing the procedure is that during cont-CPR there is no break in chest compressions, as the breath, or in this case, puff of air, is administered on the upstroke of every tenth chest compression. Performing cont-CPR with the lack of break in chest compressions has been reported to be very exhausting (Ashton, McCluskey, Gwinnutt, & Keenan, 2002) when compared to performing standard CPR.

The incidence and biomechanics of occupational pain has been investigated substantially in the low back region, and to a lesser extent in the shoulder region and both of these regions are very active during CPR administration. In particular, it has been shown that manual exertions can lead to an increased risk of obtaining low back pain (LBP) (Chaffin, 1987; Coenen, Kingma, Boot, Bongers, & van Dieen, 2014; Genaidy, Waly, Khalil, & Hidalgo, 1993; Gregory, Milosavljevic, & Callaghan, 2006; Kerr et al., 2001; Meyers & Keir, 2003; Verbeek et al., 2012; Xu, Bach, & Orhede, 1997) and shoulder pain (Bodin et al., 2012; van der Windt et al., 2000) in many manual labour-intensive professions. Further, within the health profession, complaints of LBP related to tasks performed at work have been substantial (Aasa, Barnekow-Bergkvist, Angquist, & Brulin, 2005; Marras, Davis, Kirking, & Bertsche, 1999; Smedley et al., 2003; Smith, Wei, Zhao, & Wang, 2004; Wong, Teo, & Kyaw, 2010). Emergency responders, including firefighters, paramedics, and police officers, require a high degree of fitness due to the physically demanding nature of the occupations. Not only is it required of these individuals to be in good physical shape in order to perform their job sufficiently, but the victims they are attending to depend on how well these workers perform the procedures that their profession demands. Although certain procedures are performed more often than others, each is just as important as the next. CPR may not be the most frequently administered procedure, but is nonetheless an extremely important procedure to perform efficiently as it is very exhausting (Jones, 2004; Trowbridge et al., 2009).

From an ergonomic perspective, this study aimed to investigate the biomechanical demand of the two different compression-ventilation ratios of CPR on the low back and upper limb of emergency responders and civilians performing the procedure. Although unaffiliated with this study, the motivation behind this project stemmed from an ongoing study by the Resuscitation Outcomes Consortium (ROC) investigating the performance of cont-CPR as compared to standard CPR in the field during actual emergency situations. To the knowledge of the author there have been no biomechanical studies that have recreated conditions (duration and frequency of CPR performance) under which emergency responders perform CPR, simulating a three-person rescue team.

This study tested four hypotheses: first, chest compression force applied to a CPR training mannequin would decrease across two minutes of CPR and that the rate of chest compression force decline would be greater during the cont-CPR condition compared to the standard CPR condition. Second, individuals would report increased perceived fatigue (measured as an increase in rating of perceived exertion) and low back muscle fatigue (measured as a decrease in median power frequency of lumbar erector spinae) following both CPR conditions, but that this would be greater in the cont-CPR condition when compared to the standard CPR condition. Third, muscle activation levels in the low back and upper limb would increase during the CPR trials, and that this increase would be greater in the cont-CPR trials. Finally, that low back flexion would increase over the two-minute CPR trials and that this increase would be greater in the cont-CPR condition when compared to the standard CPR condition.

1.1 ROC-CCC and Motivation for the Current Study

Medical personnel perform the CPR type that is protocol at their place of employment (paramedic service, fire station, hospital, nursing home, etc.). However, debate persists as to which type of CPR, standard or cont-CPR, is more effective in reviving a victim after an out of hospital cardiac arrest (OHCA). The Resuscitation Outcomes Consortium (ROC) conducts research in the advancement of CPR administration that may increase survival rate of cardiac arrest victims. The ROC is currently conducting a study that is comparing the use of cont-CPR and standard CPR (ROC CCC study) in OHCA victims. This study has included several regions within Canada and US, with many different EMS sites in each region. For this study, each EMS site has been assigned to perform either standard or cont-CPR for the first six minutes of CPR administration, or until resuscitation, whichever happens first, during an emergency response situation. Some sites are still ongoing, whereas other sites have either concluded or been removed due to deviation from the study protocol. This ongoing ROC study served as a motivation behind the development of this study.

2.0 Review of Literature

2.1 Occupational Low Back and Shoulder Pain- Evidence

2.1.1 Occupational Low Back Pain

Certain postures may lead to high biomechanical loads acting through the low back and shoulder joints. Postures such as flexion, lateral bend, and axial twist of the trunk may increase the amount of compression and/or shear through the low back leading to an increase in the risk for obtaining a low back injury (Punnett, Fine, Keyserline, Herrin, & Chaffin, 1991). In the work by Punnett et al., the risk of low back injury increased when individuals were exposed to multiple non-neutral postures (e.g. trunk flexion in combination with lateral bend), as well as when the duration of holding these non-neutral postures increased. van Dieen et al. (1997) examined farmers harvesting radishes and studied the loads imposed on their back while kneeling compared to loads exhibited when sitting in a chair. The kneeling position displayed significantly higher low back compression and discomfort than did the seated position. This is particularly important as kneeling is a very common posture during the administration of CPR.

Low back loading that accumulates over a long period of time is known as cumulative loading, which may be due to repetitive or prolonged exposures of biomechanical loads to the low back. Sustained and/or repetitive trunk flexion in particular contributes to cumulative loading of the lumbar spine which has been shown to be a mechanism for LBP (Coenen et al., 2013; Kumar, 1990; Norman et al., 1998). Coenen et al. (2013) investigated three low back loading variables and their relationship to risk of LBP. The variables were: 1) percent of working time spent in trunk flexion; 2) number of lifts in an 8-hour work day; and, 3) number of lifts in an 8-hour work day meeting or exceeding 25 kg, each of which contribute to cumulative loading.

It was found that when the upper range of these variables were performed, i.e. when trunk flexion greater than or equal to 60 degrees was performed for greater than 5% of a work day, or when at least 25 kg was lifted more than 15 times per 8-hour work day, the risk of LBP significantly increased. In another study investigating cumulative loading, Norman et al. (1998) identified four major risk factors for occupational LBP: peak low back shear, trunk flexion velocity, lumbar spine moment and average hand force over the course of a work day. It was found that there was over six times greater risk of LBP for workers with high exposure to all four major risk factors, suggesting that increased lumbar spine cumulative load increases the risk of obtaining occupational LBP. In the case of CPR administration, trunk flexion, substantial force at the hands (applied to the chest of a victim) and repetition may contribute to the demand.

2.1.2 Occupational Shoulder Pain

A review article by van der Windt et al. (2000) evaluated 29 different studies that examined the association between physical exposure variables and shoulder pain within the workplace. The physical exposure variables that were consistent between studies in reporting an association with shoulder pain were repetitive movements, vibrations, and duration of employment. In ergonomics, repetition is one of the main risk factors for injury; therefore it is not surprising that the studies examined by van der Windt et al. found that repetitive movements increased shoulder pain reporting. A separate study by Bodin et al. (2012) surveyed over 1600 workers and found that age (≥50 years) and high perceived physical exposure, common to both men and women, were the two greatest factors that increased the risk for shoulder pain. Similar to the risk factors determined for LBP, CPR administration would also be considered likely to contribute to shoulder pain due to the repetitive nature and high physical demand.

2.1.3 Pain and Injuries in Health Care Workers

A substantial degree of research to date has documented LBP among health care professionals (Harber et al., 1985; Thomas, 1993; van der Weide, Verbeek, Salle, & van Dijk, 1999); notably the majority of this research has focused on nurses and caregivers as they show the highest prevalence of sick leave due to LBP among health care workers (Cunningham, Flynn, & Blake, 2006). Smith et al. (2004) found that nurses in China complained of numerous musculoskeletal injuries, the most prevalent being LBP, as 56% indicated they exhibited pain to this region of their body. Neck pain (45%), followed by shoulder pain (40%) were the second and third most prevalent, respectively, among the same population. Smedley et al. (2003) also investigated the incidence of neck/shoulder pain among hospital nurses. They found that neck/shoulder pain had a prevalence rate of 34% among nurses and that pulling, pushing, and reaching tasks involving objects or patients were the most common sources of their reported pain. In a similar study, Wong et al. (2010) surveyed a large sample of hospital staff and found a high prevalence (72.5%) of LBP. Significant risk factors for obtaining LBP were found to be associated with lifting objects or patients, increased frequency of lifting during an average shift, job satisfaction, job-related stress, and of particular interest, low back posture during their respective job tasks. More specifically, non-neutral trunk posture during lifting tasks that require the hospital workers to be in a flexed low back posture was found to be a significant risk factor for LBP. Non-neutral postures refer the low back and shoulder joints deviating from a neutral range of flexion/extension, lateral bend, and axial twist. In a study conducted by Marras et al. (1999), medical aids were observed transferring patients, and the postures that this line of work required of them. Transferring a patient required the aid to position themselves in such a way to maintain optimal strength, but also not put the patient in compromising positions. The work by

Marras et al. found that the specific position required by aids was a flexed low back posture, regardless if the aid was performing the transfer alone, or with another person. The reported magnitude of the low back compression values by Marras et al. was high enough to warrant more workers compensation claims than material handlers and construction workers, demonstrating the high physical demands of health care workers. Similar flexed postures are likely evident in other tasks performed by health care professions including the performance of CPR.

Although a lot of research has focused on nurses in health care, some research has shown evidence of emergency responders with LBP and shoulder pain (Aasa et al., 2005; International Association of Fire Fighters, 2000). Aasa et al. (2005) investigated the relationship between work-related aspects of emergency responders and pain to the neck/shoulder and low back regions in both males and females. Physical factors, psychosocial factors, worry about work conditions, and musculoskeletal disorders were found to contribute to low back and neck/shoulder injuries. Common to females and males was that physical work-related factors were significantly related to LBP.

In 2011, the Center for Disease Control and Prevention (CDC) conducted a survey of all emergency responders who were treated in the emergency department. It was found that the leading cause for emergency responder injuries, amounting to 41% of injuries, were due to sprains or strains; soft tissue injuries due to over-stressing the tissues. The body region with the highest number of injuries was the lower trunk including the low back and hips, which accounted for 21% of injuries. The upper back, shoulder and neck region combined accounted for 20% of injuries. Since the CDC survey was conducted on emergency responders who were treated in the emergency department in US hospitals, there was no way of accounting for the incidences where injured workers did not seek treatment and remained working on the job. It is possible that the numbers found in the survey underestimated the true injury statistics. Although, these findings were relatively consistent with the National Fire Protection Association (NFPA) 2012 report, “Firefighter Injuries in the United States”, which reported that sprains, strains, and muscular pain accounted for 55% of firefighter injuries. With exertions being the type of event that cause the greatest number of treated injuries among emergency responders, it is likely that CPR puts emergency responders at risk for obtaining an injury.

Many factors need to be considered when evaluating one’s history of injury, or a group’s history of injury, including level and frequency of physical activity, health-deteriorating habits (e.g. smoking, drugs, etc.), diet, and hygiene, among others. Due to injuries being so multi-faceted, ergonomists have developed three main factors to consider when determining how “safe” a job is, or the degree of risk an individual assumes when performing the job. The three factors are force, posture, and repetition. With regards to emergency responders, many tasks required during emergency situations require high levels of force to be exerted in awkward postures. CPR is a unique case where repetition becomes a factor, as performing chest compressions is repetitive in nature.

2.2 Previous Investigations of CPR

2.2.1 LBP, Biomechanical Demand, and Kinematics of Performing CPR

As demonstrated above, health care professionals experience LBP and shoulder pain when performing tasks and procedures while on the job. One procedure that health care professionals may encounter is CPR and pain associated with this procedure has been previously documented (Jones 2004). In the work by Jones (2004), 20% of nurses surveyed had sustained a low back injury, and 40% of this sample reported they believed their injury to be related to the administration of CPR. Since health care workers may have to perform CPR in different settings that require different postures and positions to perform the procedure, two similar studies examined different positions in which a rescuer may have to perform CPR, and how the low back kinetics and kinematics differ between three positions. Chi, Tsou, & Su (2008) examined nine emergency responders and nine nurses, while a study by Tsou, Chi, Hsu, Wu, & Su (2009) examined 22 emergency responders performing CPR in a kneeling position on the floor and while standing with a low table height and a high table height. Chi et al. found differences in head, shoulder, trunk, hip, and knee positioning between the three positions, but did not find that these differences altered chest compression force. Although Chi et al. found no chest compression force differences between the three positions, Tsou et al. found that performing CPR on a high table produced the least amount of low back compression force compared to performing CPR on a low table and while kneeling on the floor. Contrary to this, a study by Jones and Lee (2008) tested 26 female and 10 male nurses, as well as 20 male emergency responders, while performing CPR in the kneeling, standing, and bed mount positions. Since a force transducer was not used, they estimated low back compression force with the use of the Resusci-Anne Skill Reporter mannequin, which measured chest compression depth and rate. They found that performing CPR while standing produced higher low back compression, compared to low back compression while kneeling. The varying results found in this study compared to Tsou et al. could be attributed to the method of collecting force data. The force data collected by Tsou et al. was by means of a force transducer embedded in the mannequin directly under the hands during chest compressions, while Jones and Lee collected force data by having the participants kneel or stand on a force plate. Jones and Lee further found that performing CPR while kneeling produced the highest percentage of effective compressions; a compression resulting in a chest depression depth between 1.5-2 inches. This suggests that performing CPR while kneeling is the optimal position to perform this procedure, as reviving the victim is the main focus during CPR. Prior to 2010 (at the time of the study by Jones and Lee) the AHA guidelines for effective CPR stated that the chest should be depressed between 1.5 and 2 inches; the guidelines have been revised since then to state that the chest needs to be depressed at least 2 inches (Travers et al., 2010).

2.2.2 Effective CPR

In addition to CPR position variability, of greater concern when considering effective CPR performance is: 1) the ability to apply enough force to depress the chest sufficiently for optimal blood flow and chest cavity pressure differences to maximize oxygen circulation; and, 2) chest compression rate. The compression-ventilation ratio is currently under investigation to assess whether differing ratios alter the chance of survival after cardiac arrest. According to the current revised AHA guidelines for CPR administration, one needs to depress the chest by at least 2 inches at a rate of at least 100 chest compressions per minute. In response to reports of a high percentage of insufficient depth of chest compressions in out-of-hospital cardiac arrest (OHCA), a study by Tomlinson, Nysaether, Kramer-Johansen, Steen, & Dorph (2007) investigated the relationship between chest compression depth and chest compression force and found a strong linear relationship. They also found that individuals used greater chest compression force on stiffer chests, but softer chests were compressed to a greater depth when equal force was applied. Geddes et al. (2007) found chest compression force disparities between emergency responders and non-trained civilians. The civilians displayed a much lower percentage of effective chest compressions per minute. The average force applied to the sternum was found to be 269.8 N, which was lower than that found in a similar study by Gruben, Guerci, Halperin, Popel, & Tsitlik (1993), who reported an average chest compression force of 430.7 N.

The discrepancy between the two studies may be due to the method of data collection for chest compression force. Geddes et al. used a standard bathroom scale on which participants (emergency responders and civilians) performed chest compressions while Gruben et al. measured chest compression force by use of a force transducer on top of a training mannequin.

Rescuer fatigue during the administration of CPR needs to be taken into account just as much as chest compression depth. To assess this, Ashton et al. (2002) investigated the number of chest compressions across two three-minute bouts of cont-CPR in a sample of 40 doctors and nurses. Although it was found that the participants were able to perform at least 100 total chest compressions per minute, they were only able to perform 82 effective chest compressions in the first minute. Similarly, Heidenreich et al. (2006) tested a sample of medical students performing standard CPR and cont-CPR and measured the number of effective chest compressions. They found that during cont-CPR the participants were only able to perform 47 effective compressions, and even less (32 effective compressions) during standard CPR, in the first minute, which diminished with each passing minute. In a sample of health professionals who are thought to be competent in CPR administration, this speaks to the exhaustive nature of the procedure. Similarly, in a study by Jones and Lee (2008), it was found that only 66% of chest compressions were performed effectively in a sample of CPR trained individuals within the health fields when in the kneeling position. However, when these findings were separated by sex, there was a clear difference: male nurses and male emergency responders performed effective CPR during 90% of their chest compressions, while the female nurses performed effective CPR during only 42% of chest compressions.

Compression-ventilation ratio has also been shown to play a role in rescuer fatigue. Trowbridge et al. (2009) examined differences between cont-CPR and standard CPR for the following variables: 1) chest compression rate, depth, and force; 2) joint kinetics and kinematics; 3) muscle activity; 4) metabolic muscle fatigue; and, 5) perceived exertion after five and ten minutes of CPR. Performing cont-CPR, compared to standard CPR showed significantly reduced chest compression force, depth, rate, and percentage of effective chest compressions (measured as at least 100 compressions per minute with a depth of at least 1.5 inches). Each trial was 10 minutes long, but the largest effect of fatigue due to chest compression force decline was reported to be observed in the first two minutes, though they did not report the specific values. Statistical analysis was conducted on chest compression force during the first five minutes and final five minutes of CPR for CPR type (cont-CPR and standard CPR). Cont-CPR resulted in significantly less chest compression force (461 N) compared to standard CPR (472 N) during the first five minutes of CPR. The same trend was seen during the remaining five minutes of CPR where chest compression force for cont-CPR was found to be significantly lower (391 N) compared to chest compression force for standard CPR (427 N). Further, Trowbridge et al. measured both perceived and metabolic fatigue and found that perceived fatigue was higher for cont-CPR after five and ten minutes of CPR when compared to standard CPR. The same trend was observed for blood lactate levels, which was used as a measure of metabolic fatigue. Blood lactate levels were greater during cont-CPR as compared to standard CPR.

Trowbridge et al. (2009) also measured muscle activation levels and kinematics of trunk and upper limbs during both cont-CPR and standard CPR; however in both cases, the type of CPR (cont-CPR versus standard) did not have an effect. The results of this study clearly displayed the exhaustive nature of CPR over time, but more importantly demonstrated differences between cont-CPR and standard CPR that may have implications with respect to victim survival rate after cardiac arrest.

In another study, Cavus et al. (2008) examined the physiological differences to the victim between cont-CPR and standard CPR. It was found that arterial oxygen saturation increased with cont-CPR compared to standard CPR. One role of chest compressions is to create the alternating pattern of positive and negative pressure in the chest cavity, which helps expel as much oxygen out of the lungs and into the blood as possible, while the other role is to aid in continuous circulation of blood throughout the body. During standard CPR there is increased oxygen in the lungs for the chest compressions to deliver to the essential organs; however, the break in chest compressions decreases blood flow to vital organs within the body, which is likely why the work by Cavus et al. found increased arterial oxygenation during cont-CPR. It is thought that this effect during cont-CPR outweighs the loss of incoming oxygen during standard CPR, as the incoming oxygen is idle in the lungs before chest compressions resume. A field investigation is ongoing regarding the use of cont-CPR in OHCA victims compared to standard CPR, for possible amendments to AHA CPR guidelines. This trial is being run by the Resuscitation Outcomes Consortium (ROC) and is taking place in many EMS sites in Canada and USA. Closely related studies have shown some indication that cont-CPR may have more favourable outcomes regarding victim survival after cardiac arrest (Christenson et al., 2009; Iwami et al., 2012).

2.2.3 Survival Rates After CPR: An Investigation of CPR Type

Regarding CPR survival rates, literature have shown positive, but inconclusive results, in favour of performing cont-CPR instead of standard CPR, as improved outcomes have been associated with cont-CPR. A study by Christenson et al. (2009) found that survival rates after cardiac arrest were greater when a larger portion of time was spent delivering chest compressions following cardiac arrest. A similar group who investigated the use of cont-CPR in Japan

(Japanese Circulation Society Resuscitation Science Study; Iwami et al., 2012), and a recent independent study (Bobrow et al., 2010) have also found consistent results favouring the use of cont-CPR instead of standard CPR.

A Swedish study by Hasselqvist-Ax et al. (2012) compared survival rates after one month post cardiac arrest when CPR: 1) was not performed; 2) was performed by laypersons; and, 3) was performed by medically educated laypersons, and found when CPR was performed by the medically educated laypersons, the survival rate to one month was higher (13.2%) when compared to CPR performed by the non-medically educated laypersons (8.4%), as well as when CPR was not performed prior to an emergency responder arriving on site (4%). This study also found that the time from cardiac arrest until initial administration of CPR was shorter when medically educated laypersons performed CPR (3 minutes after cardiac arrest) compared to when CPR was administered by the non-medically educated laypersons (6 minutes after cardiac arrest), as well as when no layperson performed CPR and the victim had to wait until emergency responders arrived on scene (12 minutes after cardiac arrest).

The previous study was conducted in Sweden, however, and it has been shown that incidence rates of treated OHCAs differ between continents. Europe displayed the second highest incidence of emergency responder-treated OHCAs (35.0%; OHCAs in which CPR was administered by emergency responders), just behind North America (54.6%) in a meta-analysis of 67 studies from four continents (Berdowski et al., 2010). Although incidence rates of treated OHCAs differ globally, the study by Hasselqvist-Ax et al. (2012) holds merit to identify differences between various levels of CPR-educated laypersons. As displayed, there has been some indication that cont-CPR may be favourable in OHCA cases due to increased survival rates, though no studies have investigated rescuer biomechanics to gain insight into how effective individuals are performing cont-CPR compared to standard CPR.

2.3 Erector Spinae Musculature

Anatomical, physiological, and functional aspects play a role in muscle fatigue (Cardozo & Gonçalves, 2003; Johnson, Polgar, Weightman, & Appleton, 1973; Sirca & Kostevc, 1985; van Dieen, Oude Vrielink, & Toussaint, 1993). These aspects contribute to the fatigue resistance of the erector spinae muscle (Mannion et al., 1997) as well as the erector spinae muscle contribution to spinal stability (Cholewicki & VanVliet, 2002). This group of muscles is active almost all the time to stabilize/move the spine, with the exception of passive full trunk flexion, when the flexion-relaxation phenomenon is observed (Callaghan & Dunk, 2002; McGill & Kippers, 1994; Schinkel-Ivy, Nairn, & Drake, 2014; Schultz, Haderspeck-Grib, Sinkora, & Warwick, 1985). McGill, Hughson, and Parks (2000) used near infrared spectroscopy (NIRS) to measure the muscle oxygenation of the lumbar erector spinae, specifically at the L3 erector mass, at different isometric contraction intensities measured against maximum voluntary contraction (MVC). McGill et al. observed that muscle oxygenation decreased even at low levels of muscle activation. As a result, it can be hypothesized that muscle fatigue could occur in the erector spinae muscles as a result of a low level isometric contraction for a prolonged amount of time, as one would often see in various health professions. This can be observed in various hospital staff and emergency responders as they may perform CPR in a prolonged state of trunk flexion when working over a patient on a bed, gurney or on the floor as a victim of cardiac arrest may often be found.

2.4 Considerations for the Use of Electromyography (EMG)

Surface EMG is often used in ergonomics research to evaluate the occupational demand on the musculoskeletal system. While its use can be extremely informative and valuable, considerations need to be made in order to properly determine this information. One application of EMG use is the measurement of muscle fatigue (Chaffin, 1973). Muscle fatigue may be a product of metabolic processes, structural abilities (composition of muscle fibres), and energy deficiencies due to decreasing oxygen and nutrition supply to the muscles over the time of muscle exertion (Merletti, Rainoldi, & Farina, 2004).

Muscle fatigue can be predicted by use of NIRS, which quantifies myoglobin concentration (Koga et al., 2007; McGill et al., 2000), but can also be estimated by the use of surface EMG. In order to quantify muscle fatigue using EMG, the EMG signal must be both static and stochastic (random) in nature. Early studies found that decreased frequency of the EMG signal due to decreased conduction velocity (Piper, 1912) and increased amplitude of the signal due to increased motor unit recruitment and synchronized firing of these motor units (Cobb & Forbes, 1923) have been observed with muscle fatigue. This has further been supported throughout more recent years (Basmajian & De Luca, 1985; De Luca, 1985; Knowlton, Bennett, & McClure, 1951).

Different from the analysis of dynamic movement by use of linear enveloped EMG data, static EMG used to measure muscle fatigue is analysed by use of a Fast Fourier Transform (FFT) (Cochran et al. 1967; Cooley & Tukey, 1965). An FFT algorithm converts the recorded signal from the time domain to the frequency domain. The frequency content of a surface EMG signal provides insight into changes that occur as a result of muscle fatigue, particularly a decrease in conduction velocity. Specifically, a shift in the power to lower frequencies indicates muscle fatigue and is often quantified by determining the median power frequency (MdPF) of the signal (Ament, Bonga, Hof, & Verkerke, 1993; Mannion & Dolan, 1994; Nagata, Arsenault, Gagnon, Smyth, & Mathieu, 1990). A decrease in MdPF over time suggests muscle fatigue.

2.5 Purpose and Hypotheses

2.5.1 Purpose

The purpose of this study was to compare the biomechanical demand on the shoulder and low back during cont-CPR and standard CPR. Specifically, this study aimed to determine if continuously applying chest compressions alters the biomechanics of the person administrating CPR possibly affording one CPR type (cont-CPR versus standard) a performance-based advantage.

2.5.2 Chest Compression Force

It was hypothesized that peak chest compression force would decline throughout the CPR trials from 0 seconds to 120 seconds. It was also hypothesized that chest compression force decline would be greater during the cont-CPR trials compared to the standard CPR trials.

2.5.3 Muscle Activation

It was hypothesized that muscle activation amplitude of the erector spinae muscles would increase during the CPR trials due to fatigue. The muscle activation of the rectus abdominus and external oblique muscles were hypothesized to remain constant during the CPR trials. Finally, the muscle activation of the triceps brachii and pectoralis major were hypothesized to increase during the CPR trials, as these muscle groups are hypothesized to significantly contribute to chest compression force production.

2.5.4 Lumbar Spine Flexion

It was hypothesized that lumbar spine flexion would increase throughout the two-minute CPR trials, and that the increase in spinal flexion would be greater during the cont-CPR trials compared to the standard CPR trials.

2.5.5 Low Back Fatigue

It was hypothesized that the MdPF of the lumbar spine muscles would decrease post-CPR trials compared to pre-CPR trials indicating muscle fatigue. Further it was hypothesized that the decrease in MdPF would be greater in the cont-CPR trials compared to the standard CPR trials.

2.5.6 Perception of Exertion and Discomfort

It was hypothesized that perceived level of exertion and all measures of the participant’s perceived ratings of discomfort would increase post-CPR trials compared to pre-CPR trials, and that the increase would be greater during the cont-CPR trials compared to the standard CPR trials.

3.0 Methodology

3.1 Participants

Fifteen participants were recruited for this study. Three firefighters, six paramedics, and one police officer comprised the emergency responder population, and two lifeguards and three students comprised the civilian population. Each civilian held valid CPR certifications at the time of data collection. Eight males and seven females participated in this study, and demographic information is displayed in table 1.

The firefighters were recruited from the City of Kitchener Fire Department and City of Waterloo Fire Department. The Deputy Fire Chief for each fire department was first contacted to gain consent. Once consent was gained from the respective Deputy Chiefs, the recruitment information was distributed to members of fire suppression in the fire departments. Paramedics were recruited individually via email correspondence, as were civilian participants. Participants were excluded if they had suffered from LBP or shoulder pain in the previous 12 months that required them to see a doctor and/ or take time off work.

Table 1. Demographic data of the 15 participants who completed this study; mean (±1SE).

	n	Height (cm)	(±1SE)	Weight (kg)	(±1SE)	Age (yrs)	(±1SE)	Emergency Responders (#)			Civilians (#)	
								Firefighter	Paramedic	Police	Lifeguards	CPR-cert.
Male	8	182.88	(1.73)	87.01	(5.24)	37.38	(5.37)	3	2	1	1	1
Female	7	165.16	(2.47)	65.38	(3.12)	31.29	(3.66)	0	4	0	1	2
Total	15	174.61	(2.76)	76.91	(4.19)	34.53	(3.32)	3	6	1	2	3

3.2 Materials and Instrumentation

3.2.1 Electromyography (EMG)

Muscle activation was measured via surface EMG. Pairs of Ag-AgCl electrodes were adhered to the skin bilaterally over the lumbar erector spinae (LES), thoracic erector spinae (TES), rectus abdominus (RA) and external oblique (EO) muscles of the trunk with the following placements: 3cm lateral to L3 spinous process for LES, 5cm lateral to T9 for TES, 3cm lateral to umbilicus for the RA and 15cm lateral to umbilicus for the EO (McGill, Norman, & Cholewicki, 1996). Upper extremity muscle activity was collected by placing electrodes bilaterally over the pectoralis major (PM) muscle and lateral head of the triceps brachii (TB) muscle. EMG signal processing is described below in section 3.3.5.

3.2.2 Kinematics

To capture motion data, an electromagnetic motion capture system (Liberty, Polhemus, Colchester, Vermont) was used. Two sensors were placed on the spine at the L5/S1 (lumbosacral) joint and T12/L1 joint. This placement isolated the lumbar spine to measure flexion-extension of the lumbar spine. The kinematic data were sampled at 32 Hz and dual low-pass filtered at 6 Hz with a Butterworth filter. Kinematic data were subsequently normalized to full range of flexion-extension motion (ROM).

3.2.3 Force Application

Force applied to the chest of the mannequin during CPR application was collected using a uniaxial load cell (8524-6002, Burster, Gernsbach, Germany) placed on the sternum of the mannequin. The load cell was mounted in a casing specially designed for this study, as seen in figure 1. The load cell recorded force data with a range of 0-2 kN, and data were sampled at a rate of 2048 Hz.

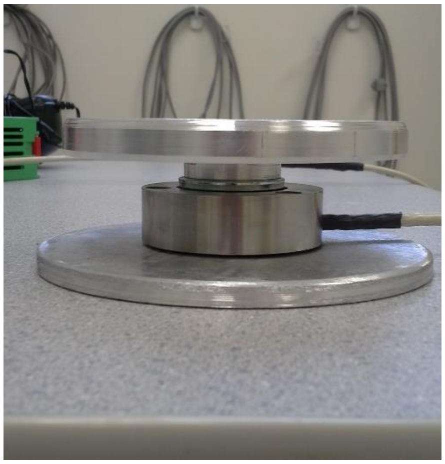

Figure 1. Lateral view of the force transducer enclosed within custom built metal plates.

3.3 Protocol

3.3.1 Apparatus

The CPR trials were performed on a CPR training mannequin torso. The mannequin was 68.58 cm in length, 33.02 cm in width across the chest, with a chest circumference of 74.93 cm, and weighed approximately 9.06 kg (Figure 2).

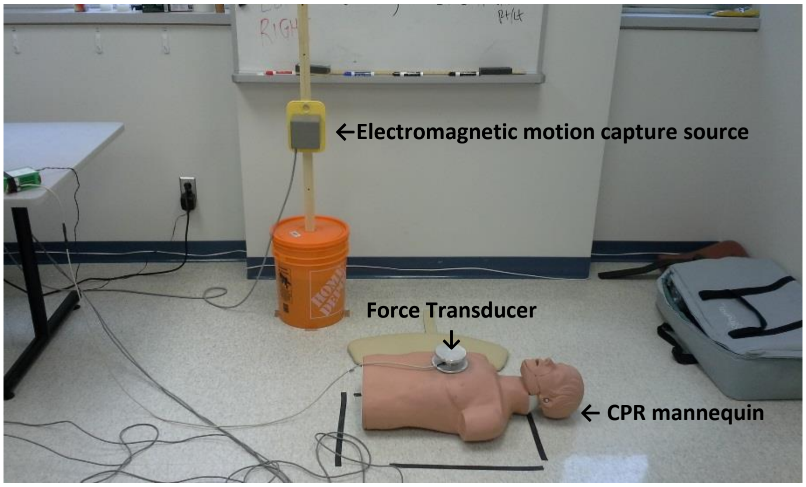

Figure 2. Experimental setup for the CPR trials. Torso mannequin with the force transducer placed on the sternum. The electromagnetic motion capture source can be seen mounted on the wooden beam.

3.3.2 Baseline Data Collection and Signal Processing

Upon arrival, written informed consent was obtained and participants were instructed to fill out a short survey (Appendix B). The firefighters filled out a slightly different survey with a few firefighter-specific questions. The survey included demographic questions, low back and shoulder injury history questions, and CPR administration questions (e.g. frequency, location typically performed, etc.). Following instrumentation with EMG, testing of all electrode connections was conducted to ensure sufficient signal acquisition. Maximum voluntary isometric contractions (MVC) for EMG normalization of the instrumented muscles were then performed. A back extensor MVC was performed by resisting a maximal effort back extension as the participants laid face down on a padded bench with their torso hanging off the end of the bench. To obtain the MVC for the TB, the participants were instructed to stand upright with their upper arm in a neutral position and elbow at 90 degrees while extending their lower arm at the elbow with maximum force against resistance. To obtain the PM MVC, with both shoulders and elbows flexed to 90 degrees, participants adducted their upper arms, bilaterally, with maximum force against resistance. Finally, to obtain the abdominal MVC, the participants sat on the bench with their hips on the edge while they faced the opposite end of the bench. The participants were instructed to lean back to 45 degrees and then perform a series of five maneuvers against the experimenter's resistance. The five maneuvers were as follows: forward crunch, right lateral bend, left lateral bend, right axial twist, and left axial twist, which were all resisted by the experimenter. Two to three trials for each MVC were collected, with a minimum of two minutes rest in between, depending on how the participant felt with regards to effort, as well as if the amplifier needed to be adjusted for any muscles. After all the MVCs were performed, a five-second EMG trial was run while the participants lay prone and fully relaxed on the MVC bench, to collect baseline EMG measures. The participants were then instrumented with the two spine motion sensors, after which they were instructed to perform a full flexion-extension ROM trial. Illustrations of all MVCs and the flexion-extension ROM trial can be found in Appendix C. An upright standing trial was also collected for five seconds to determine the neutral lumbar spine posture.

3.3.3 Assessment of Fatigue, Exertion and Discomfort

To examine the effects of CPR on back extensor muscular fatigue, the participants were instructed to perform a back extension task (Biering-Sorensen), as seen in figure 3.

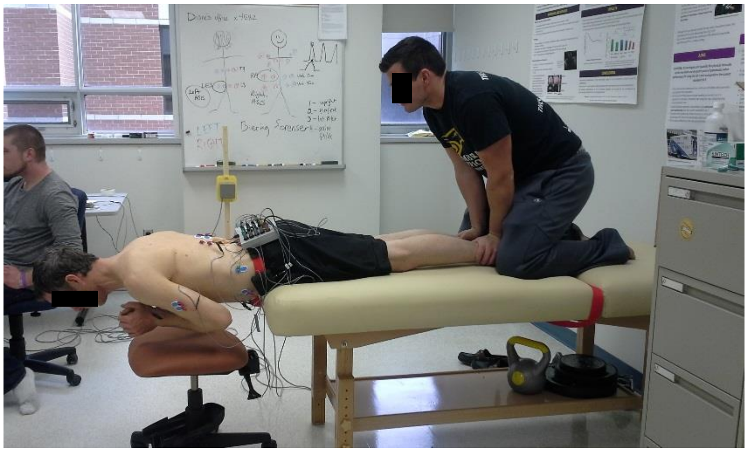
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Figure 3. Illustration of the Biering Sorensen back extensor fatigue test. The participant is holding a back extension parallel with respect to the ground, against gravity.

The Biering-Sorensen test is a static, weight-bearing test in which the participant lays face down on a bench, with their torso off the end of the bench. When instructed, the participant extended their torso so it was horizontal and parallel with the ground, and held their body weight against gravity. Each back extension task lasted five seconds, and served as a measure of trunk extensor muscle fatigue (discussed later in section 5.4.2.1) from the CPR trials. EMG data were recorded for this test. The Biering-Sorensen test was performed at four separate points during the data collection protocol (see figure 4) and was used to assess muscle fatigue before and after performance of the CPR trials. After the completion of each back extensor test, participants were also instructed to fill out RPE and RPD scales (described in section 3.3.5.4) (Figures D1 and D2, respectively).

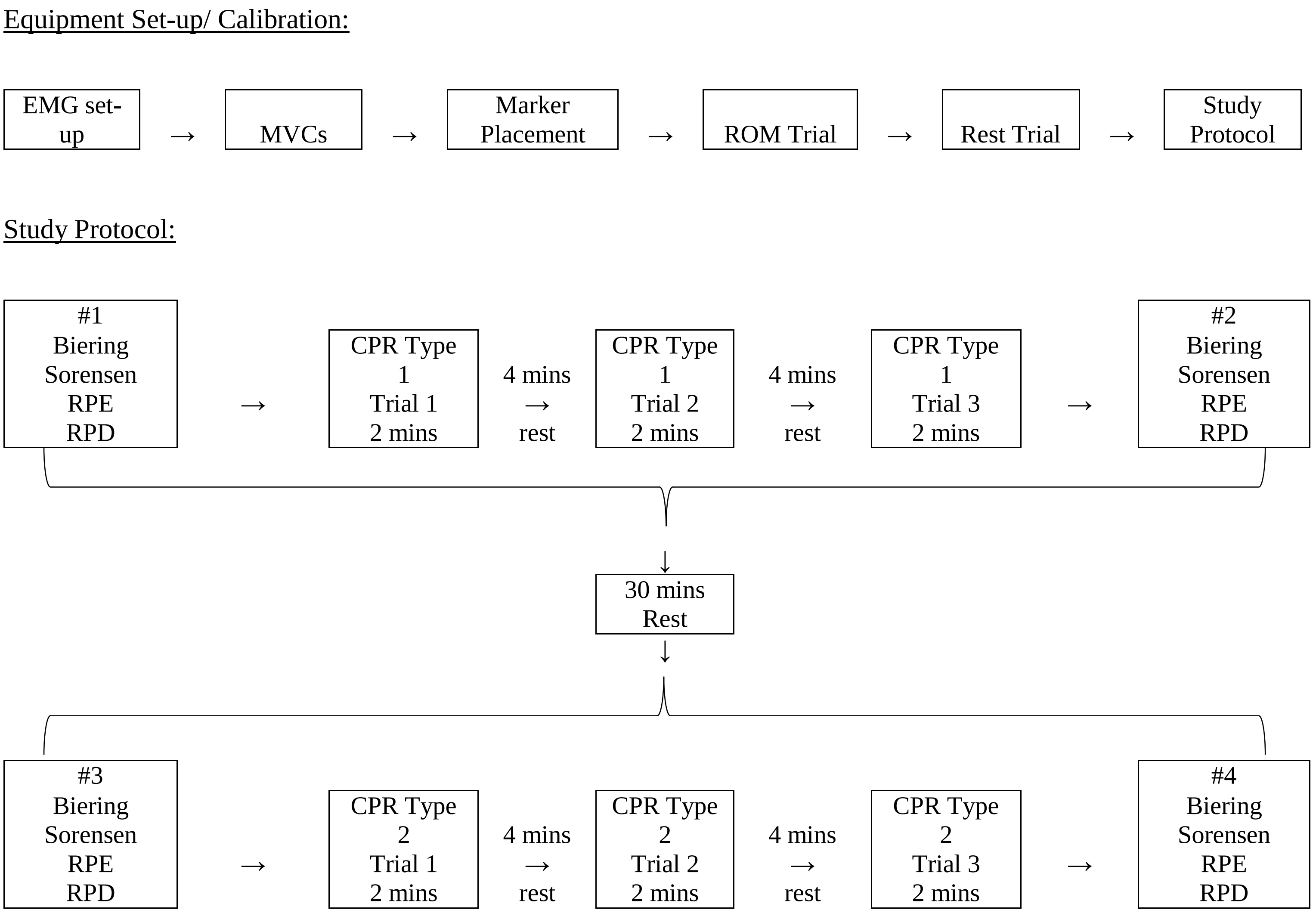

Figure 4. Flow chart illustrating the instrumentation protocol as well as the protocol for the CPR trials. The top and bottom rows of the CPR protocol illustrate the procedures for each condition, which are separated by a 30 minute rest period, indicated in between each row.

3.3.4 CPR Trials

Two CPR conditions were examined: 1) performing CPR with a compression-ventilation ratio of 30:2 (standard); and, 2) performing CPR with a compression-ventilation ratio of 10:1 (cont-CPR), for which the order was randomly assigned to the participants. Chest compressions were applied to the mannequin's chest at a rate of 100 compressions/minute for both conditions (a metronome was played throughout the two minutes). During the standard CPR trials, the participants were instructed to perform sets of 30 chest compressions. After each set of 30 compressions, each participant paused for approximately four seconds to simulate time required to administer two breaths (breaths were not actually administered). Data continued to collect during the four second pauses, which accounts for the fewer number of measured chest compressions during the standard CPR trials. During the cont-CPR trials, compressions were applied continuously without any breaks for the full two minutes. The first CPR trial was performed immediately following the first back extensor fatigue test, rating of perceived exertion (RPE) (Borg, 1990), and rating of perceived discomfort (RPD) scales. After the two minutes, the participants were given four minutes of rest, after which they performed two more minutes of CPR with the same ratio. Following this was another four minutes of rest and the final two minutes of CPR with this compression-ventilation ratio. This completed the CPR trials for the first condition. Immediately following the completion of the first condition, the participants were instructed to perform a second back extensor fatigue test, and fill out their second RPE and RPD scales. The participants were then given 30 minutes of rest. At the end of this rest period, the participants were instructed to perform the third back extensor fatigue test, and fill out their third set of RDE and RPD scales. The second CPR condition trials were then performed using the same protocol as the first condition using the second compression-ventilation ratio. Finally, immediately following the third bout of CPR for the second condition the participants were instructed to complete the fourth and final back extensor fatigue test, and fill out their final RPE and RPD scales. The two-minute CPR/four-minute rest cycle was used to represent CPR administration during a three-person rescue.

3.3.5 Signal Processing and Data Analysis

EMG data were bandpass-filtered from 10 to 1000 Hz, amplified (Bortec Biomedical, Calgary, Alberta) and sampled at 2048 Hz to ensure all frequencies were captured. Raw EMG data were subsequently full-wave rectified and low-pass filtered using a Butterworth filter with a cutoff frequency of 2.5 Hz (Brereton & McGill, 1998) to create a linear envelope of the EMG data. Linear enveloped data were further normalized to the corresponding MVC performed for each muscle group. Raw EMG signals collected from the left and right LES muscles during the back extensor fatigue tests were processed using an FFT in order to determine the frequency content, and specifically the MdPF of the signal.

3.3.5.1 Chest Compression Timing Identification

Using custom LabView software, each chest compression was determined from the force transducer data file. The software displayed the chest compression force application during the two-minute CPR trials and from this file each chest compression was identified during each two minute trial.

3.3.5.2 Muscle Activation, Lumbar flexion, and Force Data

The chest compression time points described in section 3.3.5.1 were uploaded into MatLab custom software that searched 0.25 seconds before and after each identified chest compression. Within this 0.5 second window, peak and mean force application, mean lumbar flexion and mean EMG for each muscle were identified for each chest compression during the two minute trial. These data were then arranged into a separate spreadsheet that took all the above described values (chest compression force, muscle activation, and lumbar flexion) at ten second intervals for each two-minute CPR trial for statistical analysis.

3.3.5.3 Biering Sorensen Low Back Fatigue Analysis

As mentioned in section 3.3.3, the Biering Sorensen fatigue test was a five-second static back extension test used as a measure of low back fatigue. An FFT was conducted on each trial over each of the following time points: 0-1sec, 1-2sec, 2-3sec, 3-4sec, and 4-5sec. The MdPF of the right and left LES for each second of data were recorded, and the mean value was calculated for each muscle. Determining the MdPF over each 1-sec period ensured a static signal.

3.3.5.4 Perceived Ratings Scales

As mentioned in section 3.3.3, each participant filled out four RPE and RPD scales. The four discomfort scales were measured with a ruler and inputted into a spreadsheet, and the four exertion scales were recorded into the same spreadsheet.

3.4 Statistical Analysis

3.4.1 Fatigue, Exertion and Discomfort

The results for the RPE and RPD scales and low back extensor fatigue tests were organized in one spreadsheet, and a two-way repeated measures analysis of variance (ANOVA) was conducted on these data with two factors: time (with two levels: pre and post) and condition (with two levels: standard CPR and cont-CPR).

3.4.2 Chest Compression Force, Muscle Activation and Lumbar Flexion

To assess differences in chest compression force production, a two-way repeated measures ANOVA was conducted with factors condition (with 2 levels: standard CPR and cont-CPR) and time point (with 13 levels: 0, 10, 20, 30,…, 120 seconds). To determine differences in muscle activation and lumbar flexion, a two-way repeated measure ANOVA was conducted with factors condition (with 2 levels: standard CPR and cont-CPR) and time point (with three levels: 0, 60, and 120 seconds). Tukey’s post-hoc multiple comparisons were conducted to examine any significant findings.

4.0 Results

4.1 Survey

4.1.1 Presence of LBP and Shoulder Pain

As shown in table 2, while all participants had been free of LBP within the previous 12 months, nearly one third of emergency responders had a history of LBP. Of the same population, 40% experience current shoulder pain. Further, while all emergency responders have had to perform CPR in the past, figure 5 shows that the majority of emergency responders perform CPR less than three times per month.

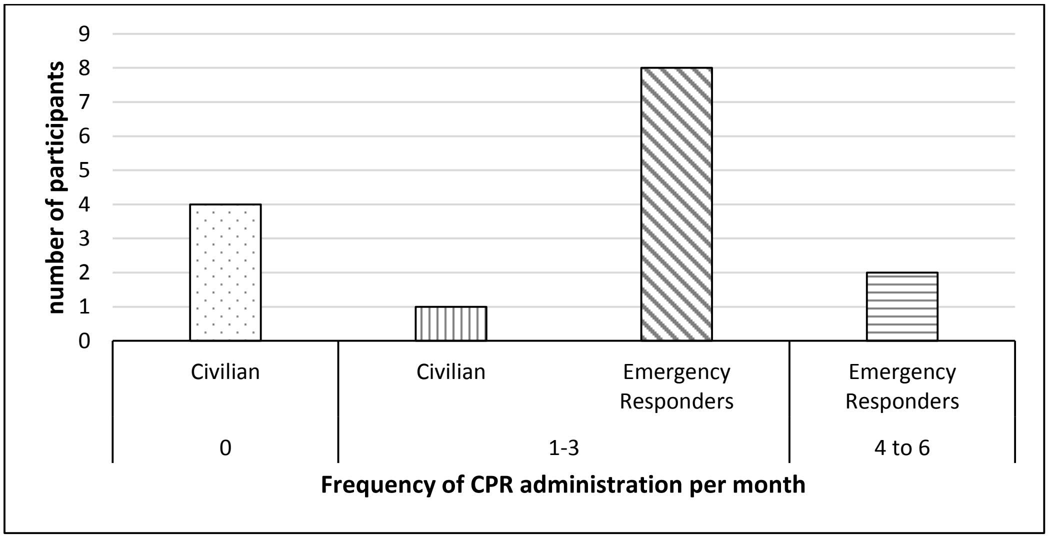

Figure 5. Frequency of CPR administration per month for each group. No civilian participant performed CPR more than three times a month, and all emergency responders performed CPR at least once a month.

Table 2. Percentage of participants with history of LBP and their self-reported current pain to other regions of the body.

Profession	Gender	n	LBP History	Shoulder Pain	Wrist Pain	Elbow Pain	Hip Pain	Knee Pain
Emergency Responders	Male	6	33%	50%	0%	0%	0%	50%
	Female	4	25%	25%	25%	0%	25%	25%
	Total	10	30%	40%	10%	0%	10%	40%
Civilian	Male	2	50%	100%	0%	0%	50%	0%
	Female	3	0%	66.67%	33.33%	0%	0%	0%
	Total	5	20%	80%	20%	0%	20%	0%
All	Total	15	26.67%	53.33%	13.33%	0%	13.33%	26.67%

The severity of the participants current LBP as well as their average LBP experienced over their lifetime was low, as seen in figure 6. This is not entirely surprising as one of the exclusion criteria was that individuals had to be at least 12 months free of LBP, prior to participation in this study, to the extent that their LBP caused the individual to seek medical care or take time off work.

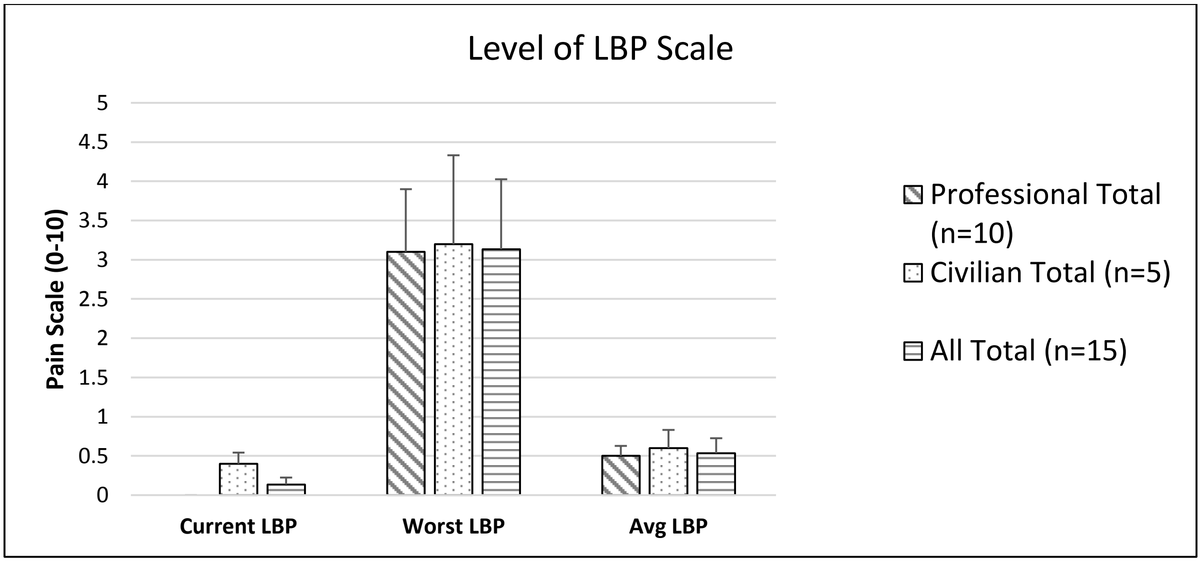

Figure 6. Mean (SE) of self-reported levels of LBP of the participants, separated by profession.

Of all the participants who reported LBP, none believed their pain to be caused or exacerbated by the performance of CPR. This result was consistent for the individuals who indicated they experience shoulder pain, as these individuals did not believe CPR caused or exacerbated their shoulder pain, though the incidence of shoulder pain was much higher; over half (53%) of participants indicated they experience shoulder pain.

4.2 Force

4.2.1 Effect of Time

Chest compression force production was measured and compared at 10-second intervals over each 2-minute CPR trial (e.g. 0, 10, 20,…, 120 seconds). When collapsed across CPR type, the chest compression force at the beginning of the CPR trials (time 0 seconds; mean=595.1 N (SE=43.8)) was significantly greater ($p<0.0001$) when compared to the chest compression force at the end of the CPR trials (time 120 seconds; mean=534.1 N (SE=39.7)), as seen in Figure 7.

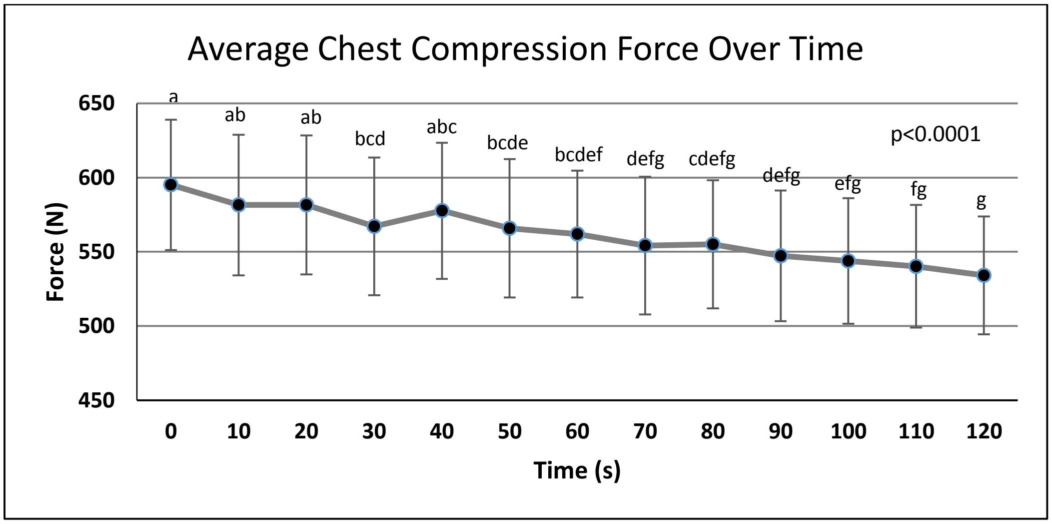

Figure 7. Mean (±SE) chest compression force across time, collapsed over CPR Type. The different letters represent significance between time points.

When chest compression force was separated by CPR type, the same trend was observed, though when collapsed across time, there was no main effect of CPR type (p=0.579); figure 8. Note in the cont-CPR condition, the average chest compression force began to decline immediately while in the standard CPR condition, the initial applied force was maintained until approximately 40 seconds into the trial (significant interaction between CPR type and time; p= 0.011). The shaded area indicates the chest compression force range required to depress the chest an optimal 1.5-2 inches (note that current AHA CPR guidelines state 2 inches for chest depression) as determined by Geddes et al. (2007).

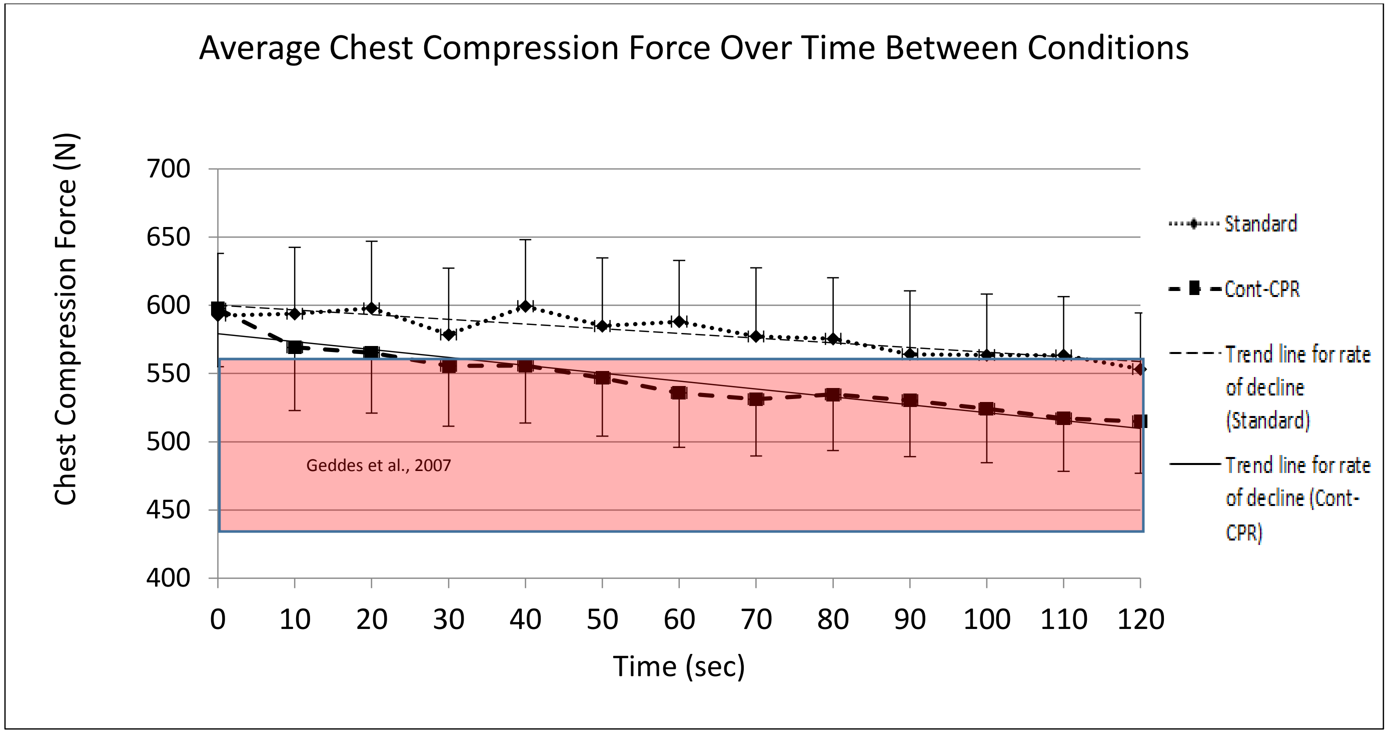

Figure 8. Mean (±SE) chest compression force at 10 second time points for both the standard trials and cont-CPR trials collapsed across all participants. The rate of force decline is displayed by the trend lines. The rate of decline during the standard CPR trials was 0.34N/sec and 0.58N/sec during the cont-CPR trials. Shaded region represents force required to depress the chest 1.5 inches (lower end of rage) to 2 inches (upper end of range and current AHA standards) as reported by Geddes et al., (2007).

When emergency responders and civilians were separated, a similar trend between the two CPR types was observed; however, a notable difference in the magnitude of force was evident; emergency responders applied a much greater chest compression force compared to civilians, as seen in figures 9 and 10.

The difference in chest compression force was very apparent as most civilians were not able to sustain enough force to depress the chest sufficiently throughout the two-minute CPR trials in both standard and cont-CPR conditions, as seen in figure 9. Conversely, most emergency responders, seen in figure 10, were able to meet and exceed the amount of force needed to depress the chest sufficiently.

During standard CPR for all participants, the rate of force decline was 0.34N/sec, whereas the rate of force decline during cont-CPR was 0.58N/sec over the two minute trials. As mentioned above, chest compression force during standard CPR was maintained relatively constant until approximately 40 seconds. When these data were not considered, the rate of decline after the first 40 seconds (0.48N/sec) was closer to the rate of decline during cont-CPR (0.58N/sec) (Figure 11). This is discussed further in section 5.4.3.

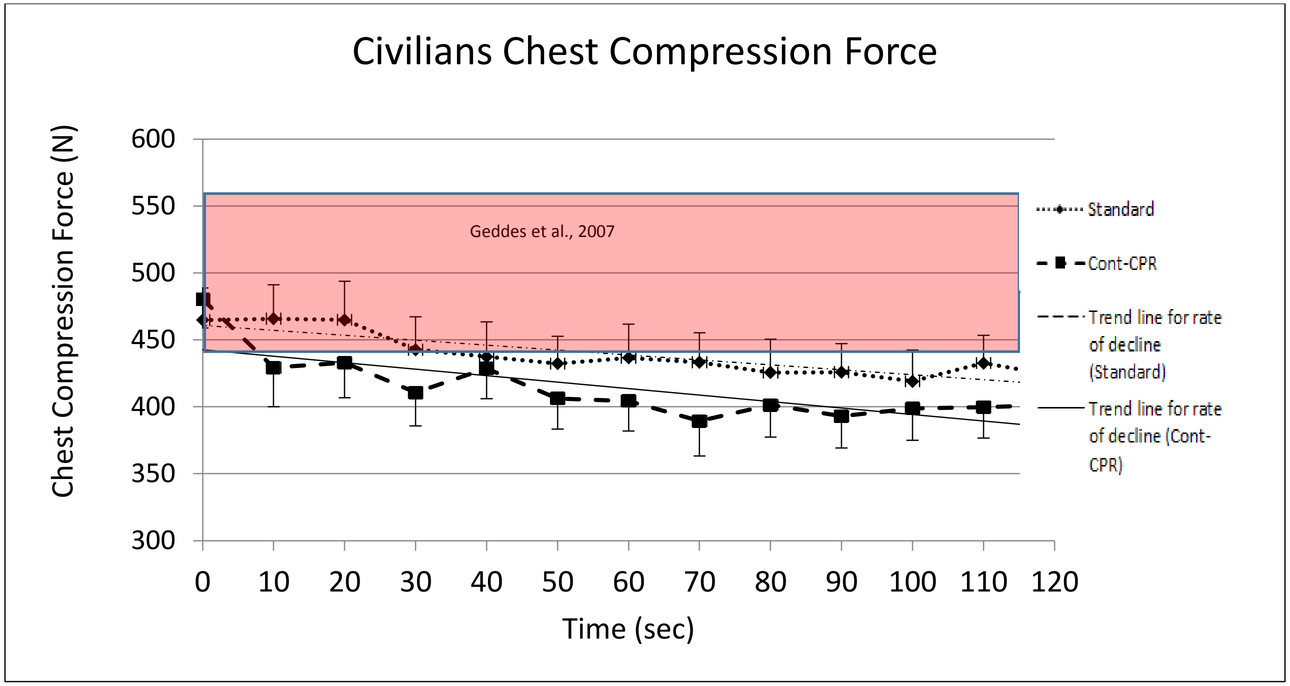

Figure 9. Mean (±SE) chest compression force output across time for both standard and cont-CPR conditions for the civilian participants. Rate of chest compression force decline for standard CPR was 0.37 N/sec and 0.48 N/sec for cont-CPR. Shaded region represents force required to depress the chest 1.5 inches (lower end of rage) to 2 inches (upper end of range and current AHA standards) as reported by Geddes et al., (2007).

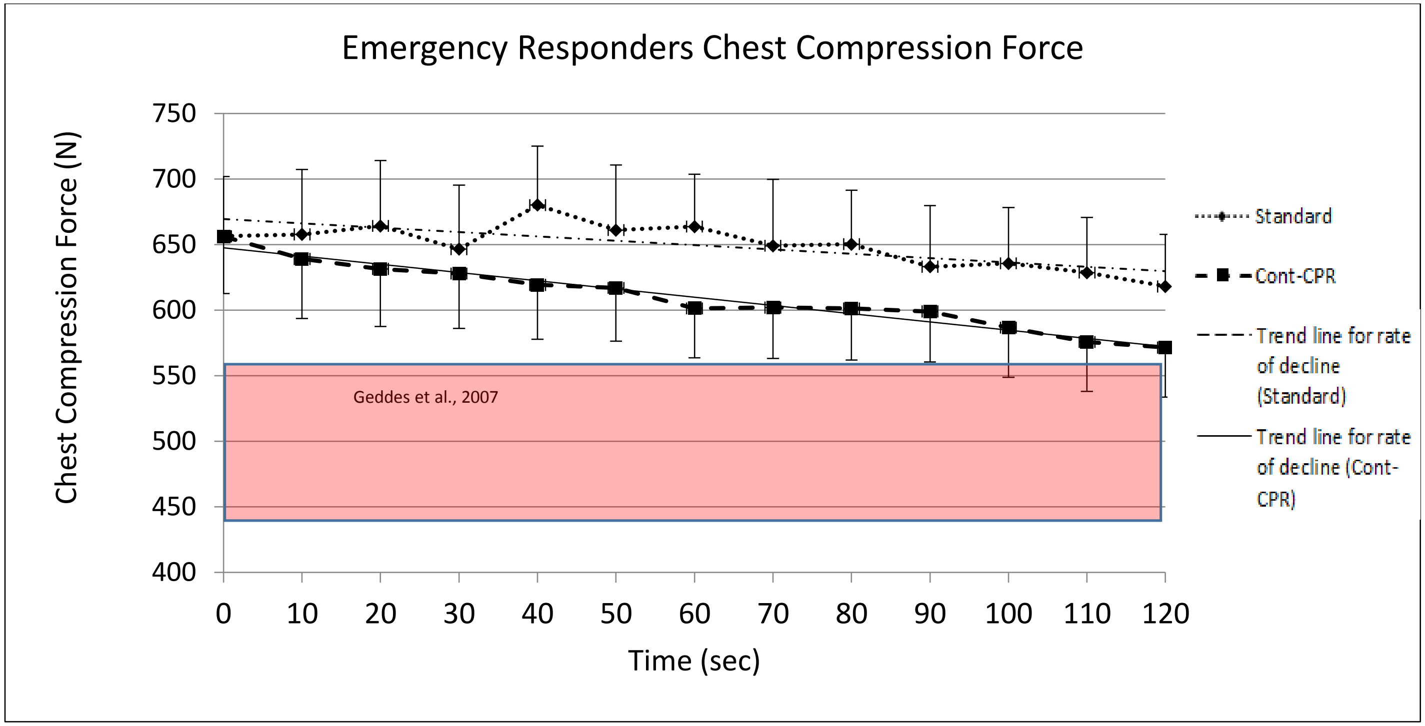

Figure 10. Mean (±SE) chest compression force output across time for both standard and cont-CPR conditions for the emergency responder participants. Rate of chest compression force decline for standard CPR was 0.33 N/sec and 0.63 N/sec for cont-CPR. Shaded region represents force required to depress the chest 1.5 inches (lower end of rage) to 2 inches (upper end of range and current AHA standards) as reported by Geddes et al., (2007).

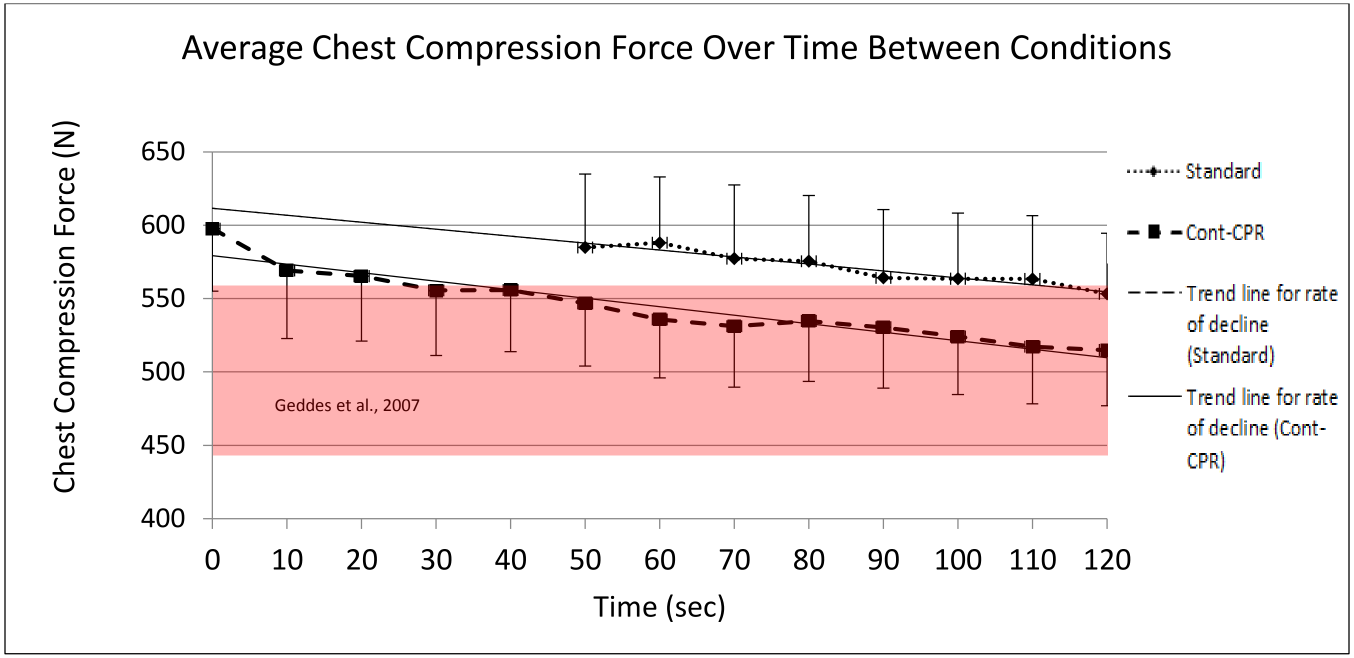

Figure 11. Mean (±SE) chest compression force at 10 second time points for both the standard trials and cont-CPR trials collapsed across all participants. Note that data from time 0-40 seconds (the region of constant force application) were removed from the standard trials in order to evaluate the declining force trend. The rate of force decline is displayed by the trend lines. The rate of decline during the standard CPR trials was 0.48N/sec and 0.58N/sec during the cont-CPR trials. Highlighted

4.2.2 *Effect of CPR Type*

No significant effect of CPR type (p=.579) was found when collapsed over time, as seen in figure 12.

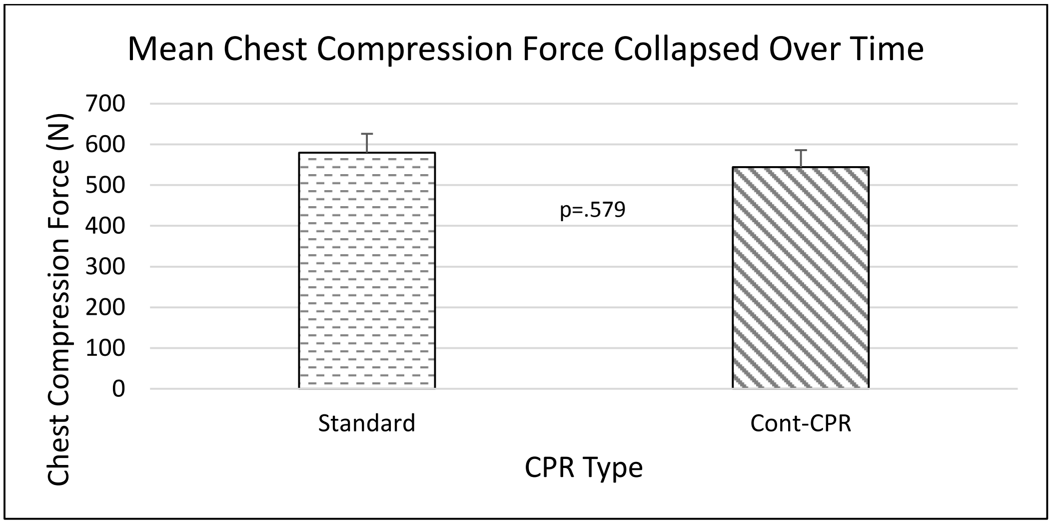

Figure 12. Mean (±SE) chest compression force for each CPR type collapsed across time.

4.2.3 *Interaction Between Time and CPR Type*

Though no main effect for CPR type was found, there was a significant interaction between time and CPR type (p=0.011), as seen in figure 8.

4.3 Electromyography

4.3.1 *Effect of Time*

The activation of six muscles bilaterally (total of 12 muscles) was measured during the CPR trials. The muscle activation for all 12 muscles was compared at three time points: 0 seconds, 60 seconds, and 120 seconds. When the data were collapsed over CPR type, statistical significance was found in five muscles, and close-to-significance (p=.051) was found in one muscle, and the remaining six were not statistically significant (figure 13).

Both the left and right LES muscles increased in activation over time (p= 0.025 and 0.04, respectively) while left and right EO decreased over time (p = 0.047 and 0.051, respectively). Last, the left PM increased over time (p = 0.017) while the left TB decreased over time (p = 0.02). In most cases, however, the change in activation observed over the two minutes was only approximately 1-2% MVC with the exception of left TB where the drop was approximately 3% MVC.

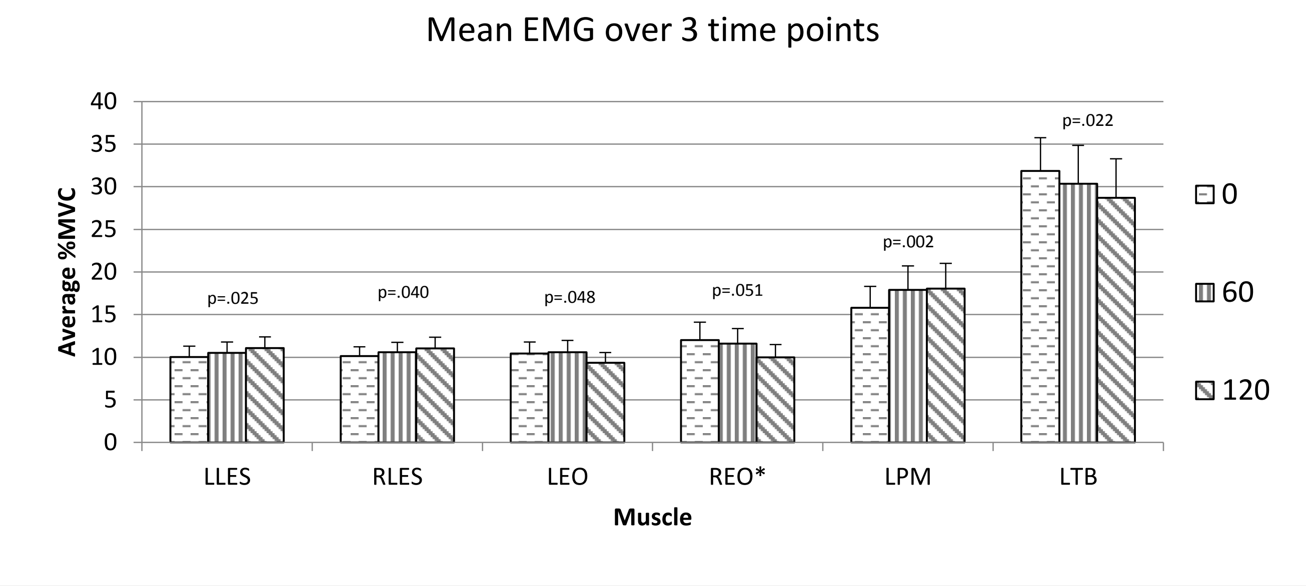

Figure 13. Mean (±SE) % MVC muscle activation at time points 0, 60, and 120 seconds for muscle where significant differences between the three time points was found. *indicates near significance. LLES and RLES= left and right lumbar erector spinae, respectively. LEO and REO= left and right external oblique, respectively. LPM= left pectoralis major. LTB= left triceps brachii.

4.3.2 Effect of CPR Type

No significant effect of CPR type was found for any of the muscles tested as seen in figure 14.

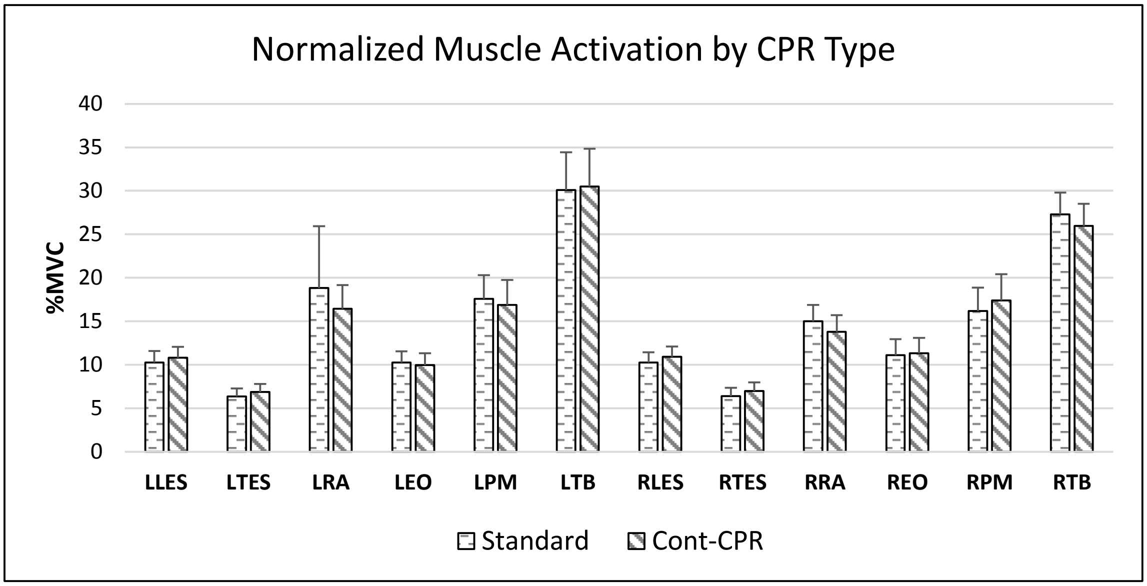

Figure 14. Mean (±SE) % MVC muscle activation collapsed over time for all muscles. No significance was found.

4.3.3 Interaction Between Time and CPR Type

A significant interaction between time and CPR type was found for the left EO muscle (p=.019). As seen in figure 15, the interaction occurs between time point 0 seconds and time point 60 seconds for the left EO muscle.

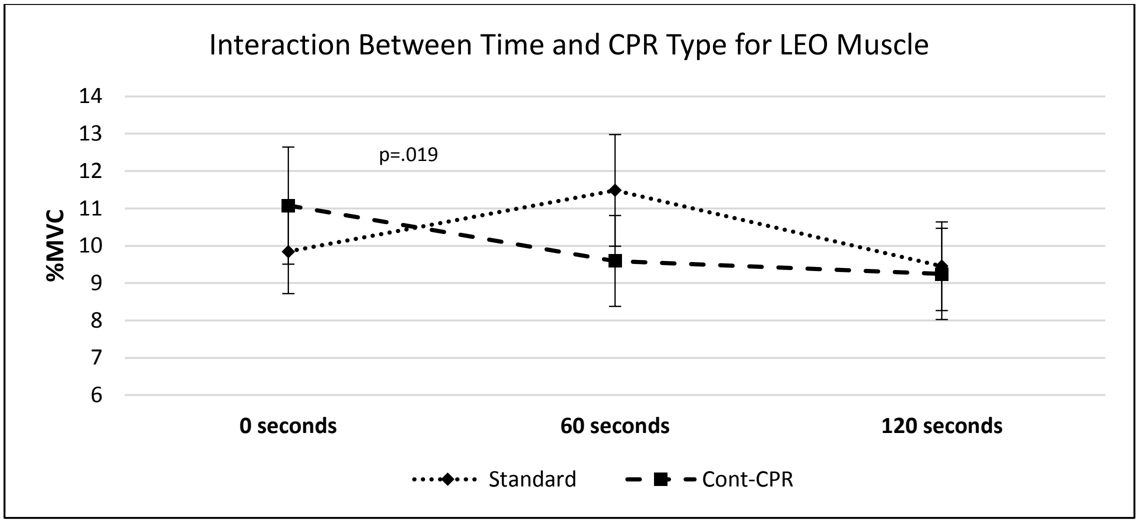

Figure 15. Mean (±SE) % MVC muscle activation of left EO for the interaction between CPR type and time.

4.3.4 Examination of Muscle Activation during Cont-CPR Trials

In figure 8, it was observed that the chest compression force during the cont-CPR trials immediately began to decline after the initial measurement at 0 seconds, compared to the standard CPR trials where a relatively constant force output was maintained for 40 seconds after the initiation of CPR administration. When only the cont-CPR trials were examined, it was observed that the left TB muscle displayed a steady decrease in activation from 0 seconds to 120 secs (p = 0.021; figure 16) that was not evident in the standard CPR trials. During the cont-CPR trials, all other muscles did not exhibit significant changes in activation levels over time (Appendix E, Figures E1-E11).

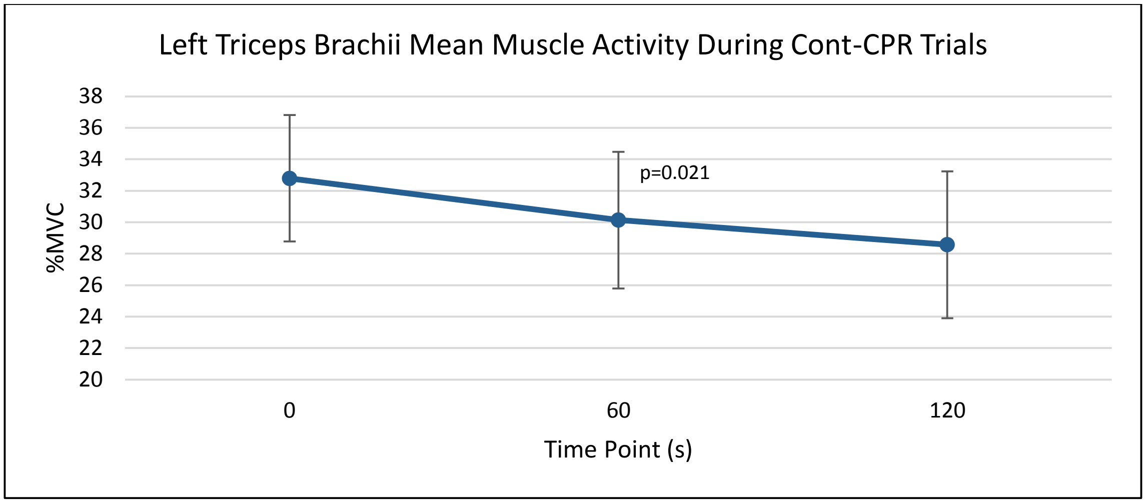

Figure 16. Mean (±SE) % MVC muscle activation over three time points (0 seconds, 60 seconds, and 120 seconds) for the left TB muscle during the cont-CPR trials only.

4.4 Lumbar Spine Flexion-Extension

4.4.1 Effect of Time

No significant effect of time (p=.685) on flexion/extension was found between 0 seconds (mean=44.77 %ROM: SE=5.77), 60 seconds (mean=46.07 %ROM; SE=5.65) and 120 seconds (mean=45.67 %ROM; SE=5.50), when collapsed over condition as seen in figure 17.

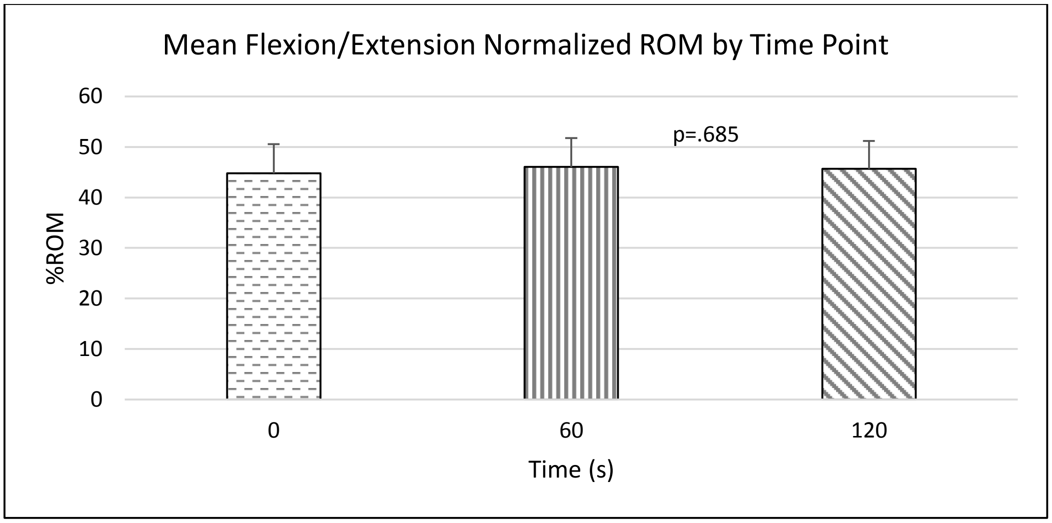

Figure 17. Mean (±SE) normalized ROM for flexion/extension of the trunk during CPR trials, collapsed over condition for all participants.

4.4.2 *Effect of CPR Type*

No significant effect of CPR type (p=.477) on flexion/extension was found between the standard trials (mean=49.44 %ROM; SE=5.67) and cont-CPR trials (mean=41.85 %ROM; SE=5.42), when collapsed over time, as seen in figure 18.

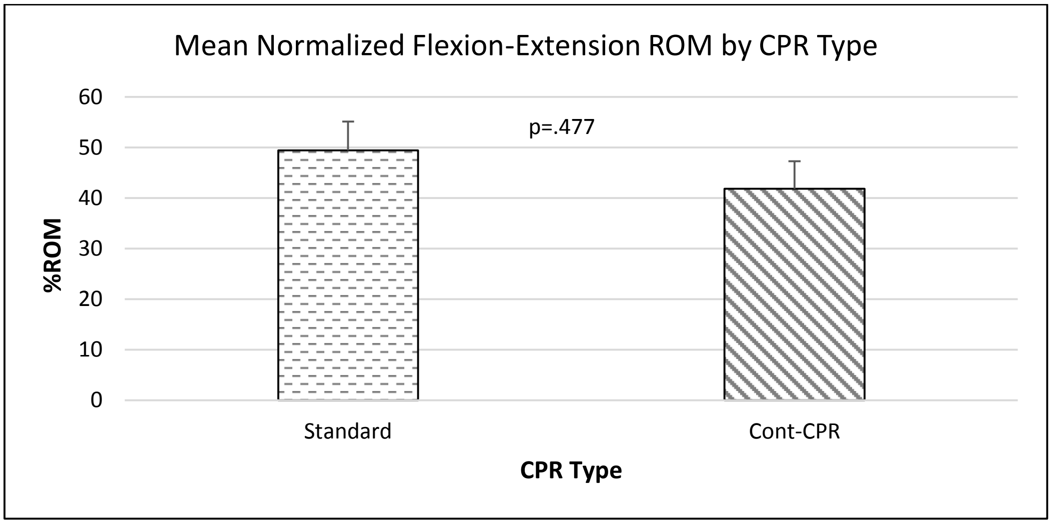

Figure 18. Mean (±SE) normalized ROM for flexion/extension of the trunk during CPR trials, collapsed over time for all participants.

4.4.3 *Interaction Between Time and CPR Type*

No significant interaction (p=.850) was found between time (with three levels: 0, 60, and 120 seconds) and condition (with two levels: standard, and cont-CPR) for lumbar flexion. Though no significant differences were found for flexion/extension, when each participant was examined individually, substantial variability was present, as seen in figure 19.

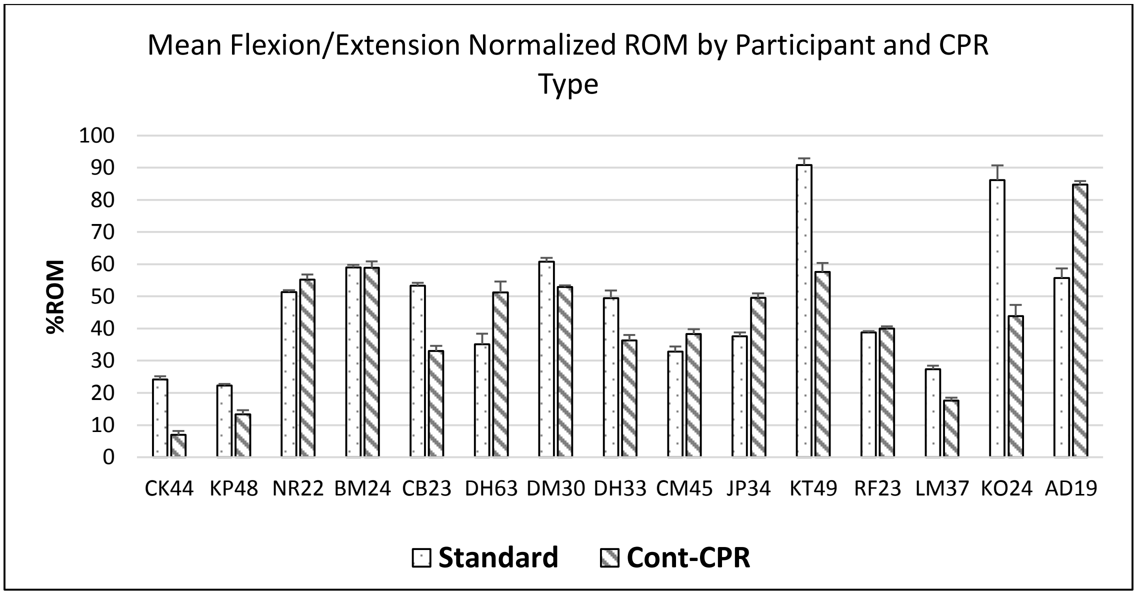

Figure 19. Mean (±SE) normalized flexion/extension ROM during the CPR trials for each participant, collapsed over time.

4.5 Fatigue, Rating of Perceived Discomfort, and Rating of Perceived Exertion

4.5.1 *Effect of Time*

When looking at the effect of time collapsed across CPR condition, all RPE and RPD variables were found to be significant with the same trend in all variables, as viewed in figure 20. Tukey’s post-hoc revealed significantly higher values following the CPR trials when compared to the values before the CPR trials in each of the following variables: All the RPD variables were measured on a scale of 0-100. Head/neck discomfort increased significantly (p=.001) from pre-CPR trials (mean=3.50; SE=1.36) to post-CPR trials (mean=7.21; SE=2.29). Shoulder discomfort increased significantly (p=.001) from pre-CPR trials (mean=4.51; SE=1.42) to post-CPR trials (mean= 12.45; SE=3.43). Upper Back discomfort increased significantly (p=.003) from pre-CPR trials (mean=3.42; SE=1.27) to post-CPR trials (mean=9.23; SE=2.96). Lower back discomfort increased significantly (p=.006) from pre-CPR trials (mean=5.80; SE=1.86) to post-CPR trials (mean=12.03; SE=3.15). Finally, overall discomfort increased significantly (p=.0002) from pre-CPR trials (mean=7.00; SE=1.95) to post-CPR trials (mean=16.57; SE=3.37). The RPE rating, which was measured on a scale from 6-20, was found to increase significantly (p<.0001) from pre-CPR trials (mean=7.87; SE=0.74) to post-CPR trials (mean=12.17; SE=0.78).

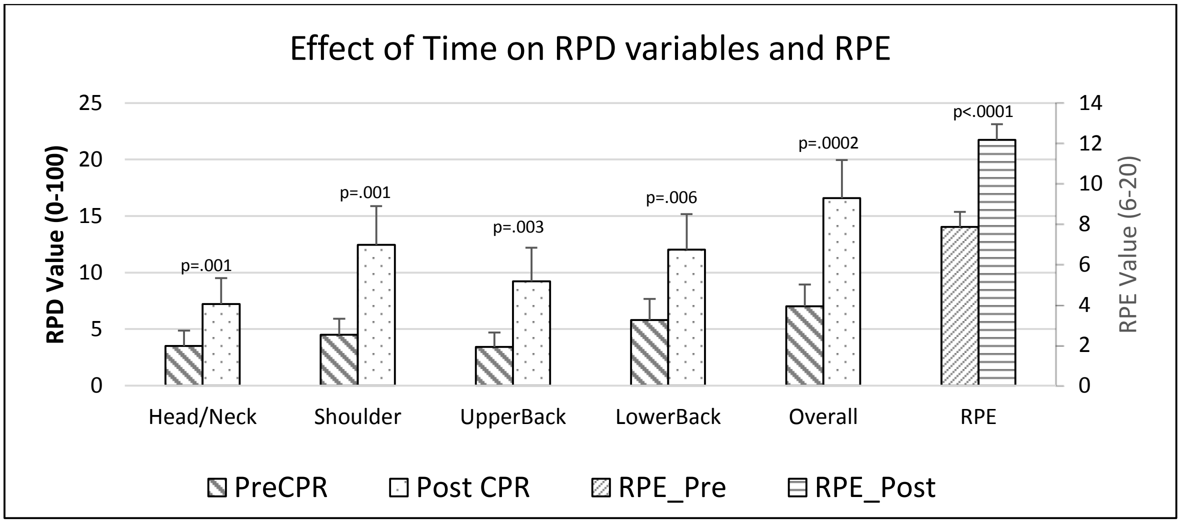

Figure 20. Mean (±SE) pre-CPR compared to post-CPR RPD and RPE values when collapsed across CPR condition.

No significant differences in left or right LES MdPF (p=.412 and p=.549, respectively) were found during the back extensor tests prior to the CPR trials (mean= 105.1 Hz and mean=108.6 Hz, respectively) compared to post CPR trials (mean=102.8 Hz and mean=106.1 Hz, respectively) suggesting no muscle fatigue as a result of CPR administration (figure 22).

4.5.2 Effect of CPR Type

No significant effect of CPR type was observed for any of the RPD or RPE variables (figure 21). Further, there were no significant differences between CPR type in MdPF, as seen in figure 22.

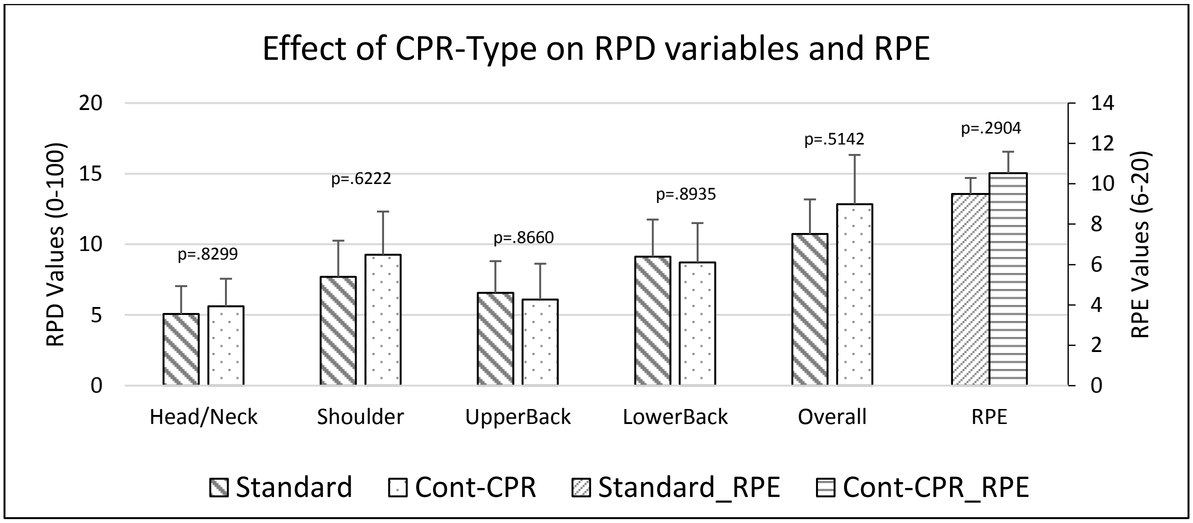

Figure 21. Mean (±SE) Standard CPR compared to Cont-CPR RPD and RPE values when collapsed across time.

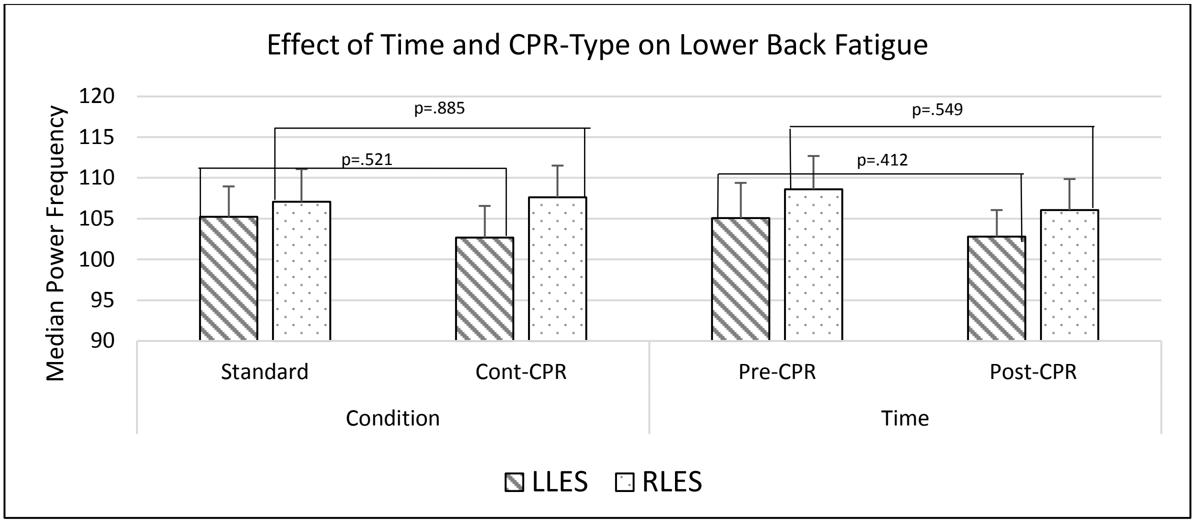

Figure 22. Mean (±SE) median power frequency both over time (pre- and post-CPR) and condition (CPR type). No significant differences were found.

4.5.3 *Interaction Between Time and CPR Type*

No significant interactions were observed for any RPD variables (figure 23 shows individual p values) or RPE scores (p=.635). Also no significant interactions between time and CPR type for left or right LES MdPF (p=.408 and p=.336, respectively) were found.

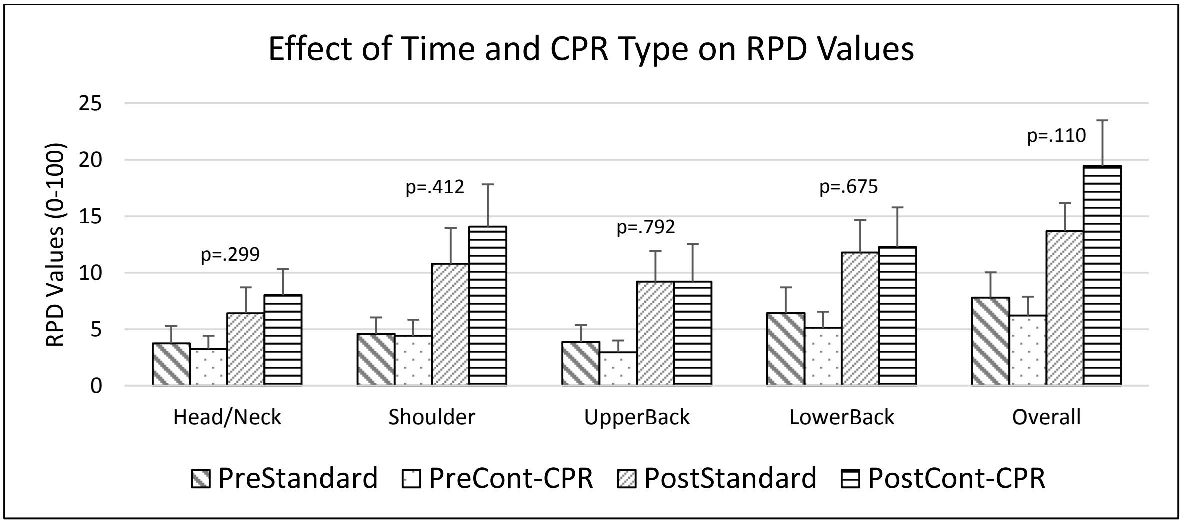

Figure 23. Mean RPD scores pre/post CPR trials and for standard and cont-CPR type. No significant interaction between any of the RPD variables were observed.

4.6 Effect of Sex on Chest Compression Force

The effect of sex as a factor in chest compression force was investigated by plotting males versus females across all participants (figure 24), civilians (figure 25), and emergency responders (figure 26). As can be seen in all three figures, males applied much greater force to the mannequin's chest.

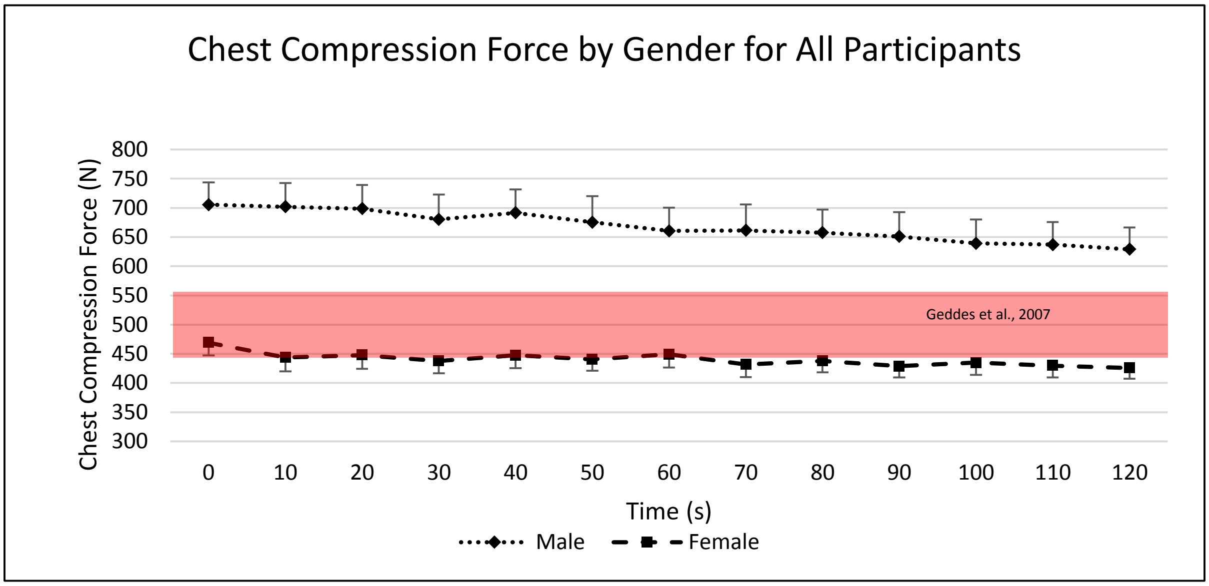

Figure 24. Mean (±SE) chest compression force output across time, separated by gender, for all participants. Shaded region represents force required to depress the chest 1.5 inches (lower end of rage) to 2 inches (upper end of range and current AHA standards) as reported by Geddes et al., (2007).

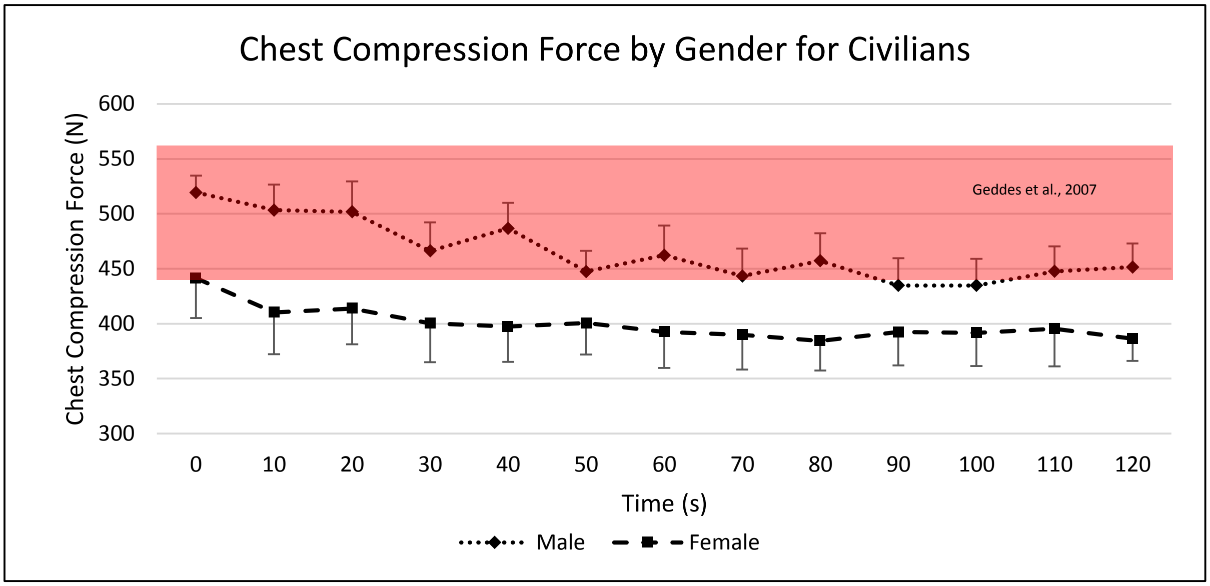

Figure 25. Mean (±SE) chest compression force output across time, separated by gender, for civilians. Shaded region represents force required to depress the chest 1.5 inches (lower end of rage) to 2 inches (upper end of range and current AHA standards) as reported by Geddes et al., (2007).

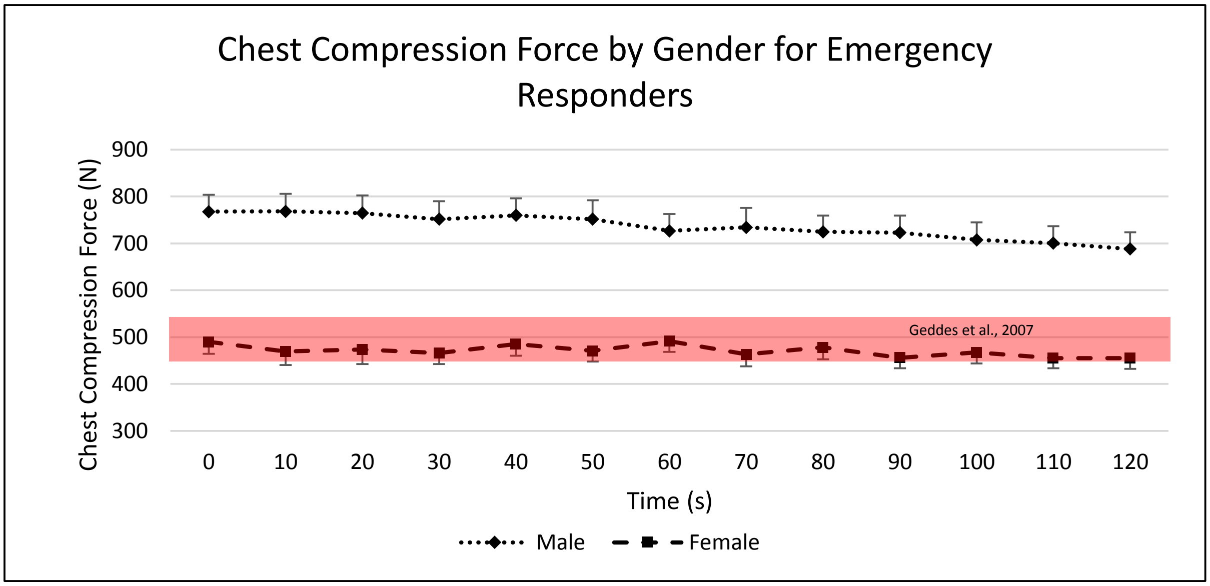

Figure 26. Mean (±SE) chest compression force output across time, separated by gender, for emergency responders. Shaded region represents force required to depress the chest 1.5 inches (lower end of rage) to 2 inches (upper end of range and current AHA standards) as reported by Geddes et al., (2007).

The chest compression force for emergency responders may have been skewed by the greater force applied by the firefighters within this population, compared to the paramedics. In order to analyze the emergency responders without the possibly skewed data by the firefighters, the same analysis was performed and plotted using data from the paramedics only, as seen in figure 27.

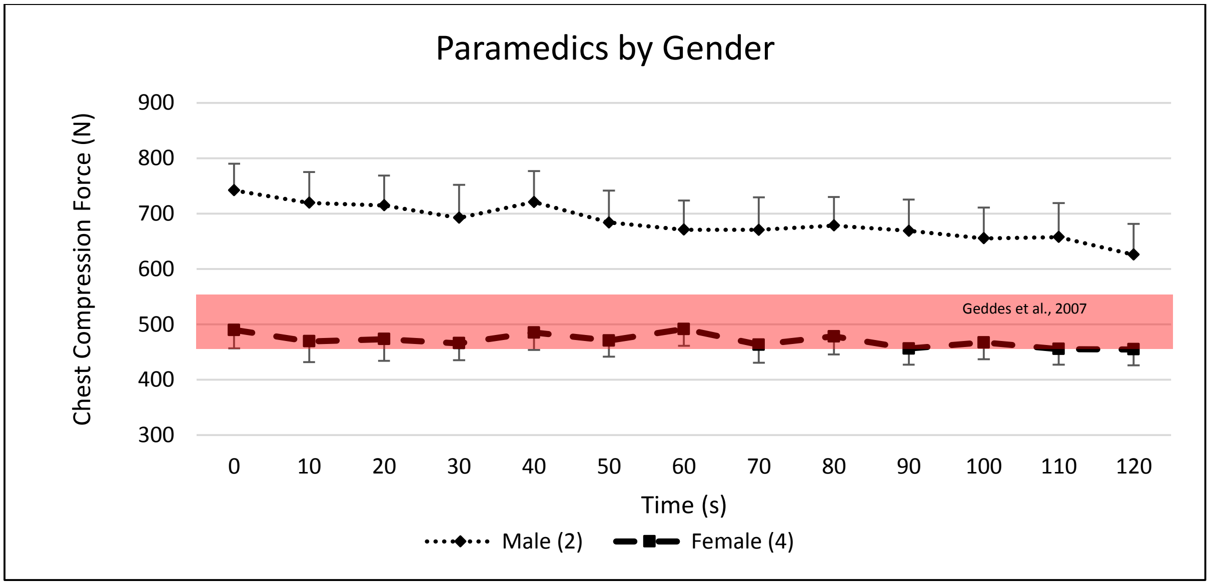

Figure 27. Mean (±SE) chest compression force output across time, separated by gender, for the paramedic participants. Shaded region represents force required to depress the chest 1.5 inches (lower end of rage) to 2 inches (upper end of range and current AHA standards) as reported by Geddes et al., (2007).

4.7 Chest Compression Force between CPR Trials

To analyze any differences between the three CPR trials, pooled across all participants, data was plotted at 0 seconds and 120 seconds for all three CPR trials. As seen in figure 28, the participants were not able to fully recover after the four minutes of rest in between each CPR trial, where the force at 0 sec for trial two was lower than trial one, and the same trend was observed for trial three compared to trial two.

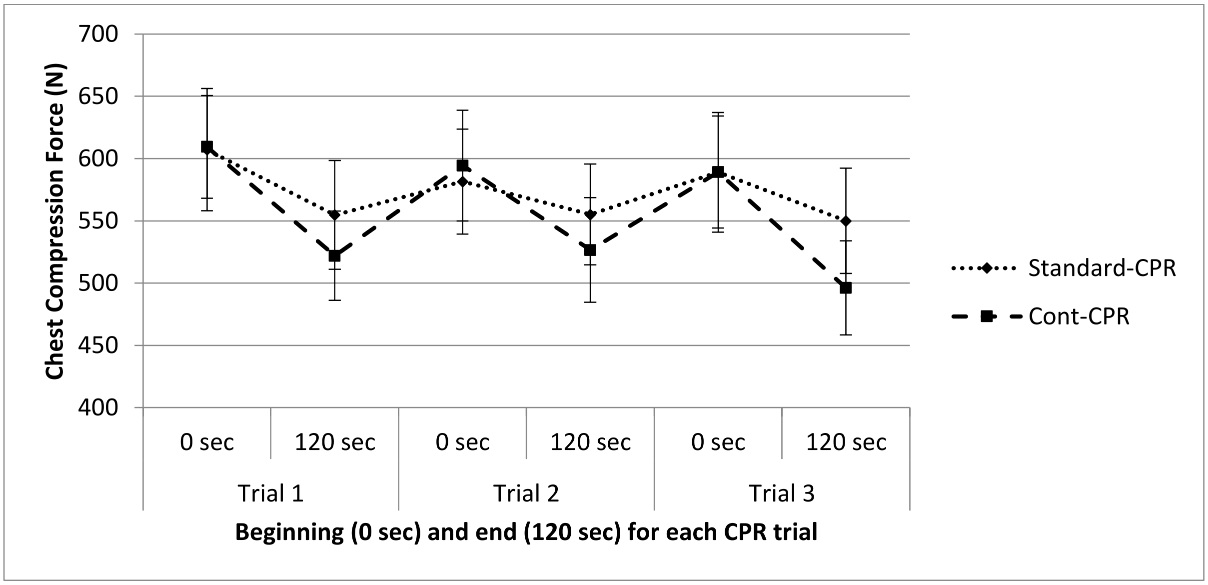

Figure 28. Mean (±SE) chest compression force output at time points 0 seconds and 120 seconds for each CPR trial, separated by CPR condition.

5.0 Discussion

5.1 Revisiting the Hypotheses

This study examined the biomechanical effect of two different types of CPR, as it pertained to the individual performing the procedure. The two types of CPR examined were the AHA standard (30:2) CPR and cont-CPR (10:1). The ROC is conducting a study investigating the use of cont-CPR compared to standard CPR by emergency responders in the field, which served as a motivation behind this study. Trunk and upper limb muscle activation, lumbar spine posture, and chest compression force were monitored during two-minute bouts of CPR administration. Additionally, low back muscle fatigue, ratings of perceived exertion (RPE) and ratings of perceived discomfort (RPD) scales were administered at four specific time points to measure fatigue and self-reported exertion and discomfort. Regardless of CPR type, chest compression force decreased significantly throughout the two minute CPR trials. Although there was no main effect of CPR type, there was a significant interaction between CPR type and time throughout the two minute CPR trials, confirming the first hypothesis. During the standard CPR trials, chest compression force remained constant for the first 40 seconds before beginning to decline for the latter 80 seconds, whereas during the cont-CPR trials, there was an immediate decline in chest compression force. Physically, the cont-CPR and standard CPR trials were identical for the first 20 seconds, so the difference between the two conditions in this time frame may indicate a psychological response to the anticipation of performing cont-CPR.

Muscle activation in the lumbar erector spinae (LES) increased over the two minute CPR trials confirming the second hypothesis, however this increase was likely not due to fatigue as a decrease in the frequency content was not observed. Rather, this increase in back extensor activity likely indicated increased lumbar spine musculature force needed to sustain the flexed posture throughout the CPR trials. With regards to the upper extremity musculature, a shift in force contribution was observed as triceps brachii (TB) muscle activation decreased while pectoralis major (PM) muscle activation increased throughout the two minute CPR trials. Significant increase in all RPD variables were found as well as significant increase in RPE scores, post-CPR trials compared to pre-CPR trials, confirming the last hypothesis. This speaks to the exhausting nature of CPR, regardless of CPR type. Although the RPE and RPD scales displayed the fatiguing nature of CPR, no corresponding difference was found for the frequency content of the erector spinae muscles during the fatigue trials pre versus post-CPR.

5.2 Chest Compression Force

5.2.1 Chest Compression Force and Ratings of Perceived Exertion Over Time

It was originally hypothesized that chest compression force would decrease over time during both standard and cont-CPR, from 0 seconds to 120 seconds. It was also hypothesized that this decrease in chest compression force would be greater during the cont-CPR trials when compared to the standard CPR trials.

The first hypothesis was validated as chest compression force decreased significantly ($p<0.0001$) from the beginning of the CPR trials compared to the termination of the CPR trials, regardless of CPR type (Figure 7). This finding aligned with the self-reported RPE scores. The individual’s RPE scores post-CPR trials were greater ($p<.0001$) than pre-CPR trials, regardless of CPR type (Figure 20). The increased RPE scores post-CPR was likely in response to increased cardiovascular demand. Previous work has shown that perceived exertion corresponds closely to actual metabolic exertion (Hogan & Fleishman, 1979; Mital, Foononi-Fard, & Brown, 1994).

The second hypothesis was also confirmed as a significant interaction between CPR type and time was observed (p=0.011). Specifically, during the cont-CPR condition, there was an immediate and steady decline in chest compression force; in contrary, during standard CPR, the participants were able to sustain a constant chest compression force during the initial 40 seconds, after which the force declined steadily from 40 to 120 secs. This was particularly evident when the rate of chest compression force decline over the 120 seconds was examined. The rate of the force decline during the cont-CPR condition was found to be 0.58N/sec while the overall rate of force decline during the standard CPR was found to be only 0.34N/sec (Figure 8). Interestingly, however, when the constant force plateau during the first 40 seconds of standard CPR was not considered, the rate of decline (0.48N/sec) became much closer to that of cont-CPR (Figure 11). Although both types of CPR were shown to be very fatiguing, as evident by the increase in RPE scores and decreased chest compression force over time, this observation of immediate force decline during the cont-CPR trials may be a direct result of not having a small break (during the administration of two breaths) after each 30 chest compressions. During the first 40 seconds of standard (30:2) CPR the participants were able to take two separate breaks in chest compressions where rescue breaths would be administered in a real-life situation. These two breaks may have been enough to prolong the performance of effective chest compressions while keeping the cadence of 100 chest compressions per minute.

The immediate decline in chest compression force before 20 seconds was surprising as there was no physical difference in administration between the CPR conditions until the first break during standard CPR, which occurred around 20 seconds. This, again, may be a result of the mental aspect of the participants knowing they have to perform chest compressions continuously for two straight minutes, anticipating the higher perceived fatiguing exercise, as discussed in section 5.3.3.

To perform chest compressions at an optimal level for effective CPR, one must use enough force to compress the chest at least two inches (AHA CPR guidelines, 2010) for adult victims, at a rate of 100 chest compressions per minute. A study by Geddes et al. (2007) found in order to perform effective chest compressions, one must compress the chest with force ranging between 445 N to 556 N, with the higher range corresponding to 2 inches of chest depression; the current AHA recommendation. When looking at chest compression force for all participants (figure 8), most, on average, reached the lower end of this range throughout the two-minute CPR trials, regardless of profession (and therefore reached, on average, 1.5 inches of chest depression). Consistent results have supported this finding, as a study by Trowbridge et al. (2009) found that chest compression force dropped from approximately 500 N at the onset of CPR to approximately 450 N after the first two minutes of CPR, indicating that most of the participants could at least reach the minimum 1.5 inches of chest depression. Though this was interesting, it was also important to separate the population into emergency responders and civilians to observe any differences, discussed in section 5.3.2.

5.2.2 Emergency Responders versus Civilians

Collecting data from both emergency responders and civilians made it possible to compare the two populations to each other. Not surprising, but interesting to see, there was a clear difference between the magnitude of chest compression force between civilians and emergency responders, as seen in figures 9 and 10, respectively. At the onset of the two-minute CPR trials, most civilians were able to apply enough force to depress the chest to 1.5 inches;

however they were not able to sustain this throughout the 2 minutes of CPR. Further, none of the civilians applied enough force to depress the chest the full 2 inches, which is the current AHA guideline (upper range of the shaded region in figure 9). This finding is significant for bystander CPR, which may give insight into the low rates of survival in OHCA patients. Although survival rates differ depending on location (Berdowski et al., 2010) they have consistently been reported to be very low; approximately 2-10% (Bobrow et al., 2010; Iwami et al., 2012; Svensson et al., 2010). Bystander CPR is incredibly important as it is imperative for the survival of cardiac arrest victims several minutes before emergency responders can arrive and continue life support, as Hasselqvist-Ax et al. (2012) found that it took approximately 12 minutes for an emergency responder team to arrive on scene and begin life support.

On the other end of the spectrum was the chest compression force of the emergency responders. Contrary to the force production by the civilians, the emergency responders well exceeded the maximum 556 N (2 inch chest compression depth) threshold during the onset of CPR in both conditions (figure 10). Though there was a decrease over time, many of the emergency responders were able to maintain the upper range of chest compression force midway through the two-minute trials, and some were able to sustain this force through to the end of the trails. Though there were differences in the amplitude of chest compression force between emergency responders and civilians, the rates of force decline are interesting to investigate. During standard CPR the rate of force decline for both emergency responders and civilian populations were very similar (0.33 N/sec and 0.37 N/sec, respectively). But when looking at cont-CPR, the rate of force decline for the emergency responders (0.63 N/sec) was much greater than that of the civilians (0.48 N/sec). This may be a direct result of the much higher magnitude of chest compression force, which appears to be much harder to sustain. This indicates that two minutes of cont-CPR may be too fatiguing even for emergency responders. The civilian results were worth further consideration for being under the threshold such that the chest compressions may not be as effective as they should be. Conversely, the results of the emergency responders were also worth investigation, as they may be exerting themselves too much and are unable to sustain effective chest compressions for two minutes of CPR. This high chest compression force being exerted by the emergency responders may also contribute to unnecessary internal damage to the cardiac arrest victim.

5.2.3 Effect of Sex

A large difference between males and females regarding chest compression force was observed. When collapsed across CPR type, males applied much higher chest compression force than females, as seen in figure 24. Males were also able to sustain sufficient chest compression force for effective CPR, as they were able to apply enough force to depress the chest at least 2 inches throughout the entire two-minute CPR trials. In contrast, females, on average, were not able to maintain enough chest compression force throughout the two-minute trials to compress the chest even 1.5 inches, which was the previous, less stringent, 2005 AHA CPR recommendations. A greater decline in chest compression force was observed for males, although this decline was not large enough for force to drop below the threshold to compress the chest at least 2 inches. As discussed previously in section 5.2.2, differences between emergency responders and civilians were observed, however, it is possible that this was in part due to a higher percentage of males in the emergency responders group. In order to determine this, data were separated by both sex and profession.

For the civilian population, males performed more forceful chest compressions than females but were not able to apply enough force to meet the current minimum AHA recommendation, though most male civilians were able to stay within the previous AHA recommended range to compress the chest at least 1.5 inches. When looking at the female civilians, most started with enough force to meet the previous AHA recommended minimum force of 1.5 inches, but this immediately dropped well below this range, as seen in figure 25.

When looking at the emergency responders, a more extreme sex difference was observed, as shown in figure 26. The males well exceeded the current minimum AHA recommendation for chest compression force at the beginning of the trials, and despite an 80 N drop in chest compression force by the end of the trials, no males dropped below the current minimum. Compared to the females, none were able to perform CPR with enough force to meet the current AHA minimum, though most, if not all, were able to stay within the previous range throughout the whole two-minute trials. These results are an indication of how difficult performing CPR is, and although there is an effect of sex, a training effect exists as the emergency responders were able to perform more effective CPR when compared to the sex-matched civilians. With regards to a training effect, it is interesting to note that male civilians and female emergency responders performed CPR with similar chest compression force, though the female emergency responders were more consistent throughout the entire two minute trials. This may be an indication that although there appears to be an effect of continuing CPR training, there also appears to be an effect of sex as males have greater average body mass and may be able to perform more forceful chest compressions simply due to being heavier.

Although this large difference was observed between emergency responders and civilians with respect to sex, it is worth noting that within the emergency responder population the firefighters performed CPR with significantly higher chest compression force compared to the paramedics. In order to observe that the above results were not skewed by the firefighters, the same analysis was performed within the paramedic population only, as seen in figure 27. Although not as high, the male paramedics were able to produce enough chest compression force to meet the current AHA recommended minimum throughout the two minute trials, and most were able to sustain this by the end of the trials. The female population was the same as noted before as all the female emergency responders were paramedics (table 1).

5.2.4 Force Across CPR Trials

To mimic a three-person emergency rescue team, the participants were given four minutes of rest in between CPR trials (figure 4). When all three trials were pooled together, a significant decrease ($p<.0001$) in chest compression force was found (figure 7). All previous chest compression force comparisons were collapsed across these three trials, however an interesting finding occurred when the three CPR trials were looked at individually. The beginning (0 sec) and end (120 sec) of all three CPR trials were separated and compared to each other. As it can be seen in figure 28, at the beginning (0 sec) of trial two the chest compression force is slightly lower compared to the beginning of trial one, and the same trend is seen when comparing the beginning of trial three to trial two. This is thought to be indicative of fatigue, where the four minute rest periods are not long enough to recover to pre-CPR trials state. Although it cannot be attributed to low back muscle fatigue, as per the MdPF results (section 4.5.2), there may be fatigue present in other areas of the body, or possibly cardiopulmonary fatigue. Though the decrease does not appear to be significant, it is important for emergency responders to recover sufficiently, whenever possible, to perform effective CPR. Interestingly, despite there being a force decline at time point 0 sec between all three trials, the participants were able to compress the chest with relatively equal force at the beginning of each trial regardless of CPR type. This indicates that despite the greater chest compression force decline during cont-CPR, the individuals were able to recover to the same point between standard and cont-CPR.

5.3 Ergonomic Analysis of CPR

5.3.1 Perceived Exertion Over Time

CPR is a very fatiguing procedure to perform effectively, as indicated by the immediate decline in chest compression force demonstrated in this study, which is consistent with Trowbridge et al. (2009) where chest compression force dropped by roughly 50 N in the first two minutes of CPR (the current study found a drop of approximately 60 N collapsed across condition; during standard CPR there was a drop of roughly 40 N across two minutes, while a drop of approximately 80 N was seen during two minutes of cont-CPR). This suggests fatigue may be significant when performing CPR for as little as two minutes at a time. A study by Heidenreich et al. (2006) measured the number of effective compressions per minute during both cont-CPR and standard CPR by use of a Resusci Anne CPR mannequin, which recorded chest compression depth. They found that the amount of effective chest compressions the participants were able to perform per minute decreased significantly from the first through the third minute, and plateaued from minutes four through nine. This supports the claim that fatigue may be significant during the first two minutes of CPR. Although not directly measured in the current study, the presence of cardiovascular fatigue appeared evident as estimated by having participants fill out RPE scales, which were collected during this study at four different time points. The participants felt they were exerting themselves much more at the end of the two-minute CPR trials than before the trials (12.2 and 7.9, respectively; $p<.0001$). Further, when collapsed over time, the participants felt they were exerting themselves more during the cont-CPR trials compared to the standard CPR trials (10.5 and 9.5, respectively); although this result was not found to be significant ($p=.29$). Trowbridge et al. (2009) found a significant increase in RPE scores across time during cont-CPR compared to standard CPR (14.5 and 13.3, respectively; p<.001). Given a larger sample size this may have been found to be significant, but the trend displays the greater degree of perceived exertion during cont-CPR trials, which is consistent with the chest compression force findings in the current study.

5.3.2 Muscle Activity

There has been limited documentation of trunk and upper extremity muscle activation levels and patterns during the performance of CPR, but this study was the first to analyse interactions between the different muscles and their contribution to the performance of CPR. It was hypothesized that LES and TES muscle activation would increase over time due to muscle fatigue, RA and EO muscle activation would remain constant, and TB and PM muscle activation would increase over time due to increasing demands to maintain sufficient chest compression force.

5.3.2.1 Erector Spinae

Supporting the original hypothesis, muscle activation of the LES increased over the two-minute trials of CPR. This increase may be due to greater motor unit recruitment for the maintenance of posture (De Luca, 1997; Fallentin, Jorgensen, & Simonsen, 1993; Pocock, Richard, & Richards, 2013) which is important during CPR. While an accompanying drop in median power frequency (MdPF) was also observed in the LES, this drop was not found to be significant, therefor the increase in LES muscle activation is not due to muscle fatigue. It is possible that this drop in MdPF would have become significant if CPR had been performed for longer than two minutes and therefore would have more closely matched the findings of increased perceived exertion. Important to note is that RPE scales represent whole-body fatigue and are not region-specific. Therefore, it is possible that the increase in perceived exertion was not reflective of low back fatigue, but rather fatigue in other regions such as the upper limb that were not examined in the currently study. Trowbridge et al. (2009) found a decrease in erector spinae muscle activation, with an accompanying increase in RPE score over time (10 minutes of CPR administration). Although Trowbridge et al. did not measure low back fatigue by analysing the power frequency domain, they deduced fatigue by means of the participant's RPE scores. The current study performed a more accurate measure of muscle fatigue, and given a larger sample size, or longer trials, the drop in MdPF in the left and right LES may have become significant.

5.3.2.2 Abdominal Musculature

The muscle activation of the RA and EO muscles was hypothesized to remain relatively constant, as it was hypothesized that the erector spinae muscles would be responsible for maintaining trunk posture during CPR; however, the EO muscles actually displayed a decrease in activation throughout the CPR trials. The RA muscles displayed a similar decreasing trend but did not reach significance. The trend in both muscles was surprising as a shift in muscle activation was observed with a decrease in abdominal muscle activation to an increase in one upper extremity muscle activation. This shift may be due to the upper extremity muscles being the primary source of chest compression force production, so the abdominal muscles are relied on less heavily to maintain enough force for effective chest compressions.

5.3.2.3 Upper Extremity Musculature

The muscle activation of the TB and PM muscles was hypothesized to increase throughout the CPR trials to compensate for fatigue in the back extensor muscles in order to maintain posture for effective chest compressions.

It was found that the activation of both the left and right TB decreased throughout the CPR trials while the left PM muscle activation increased. This inverse relationship between the two upper extremity muscles may be explained by their force production contributions to the chest compressions. When the force output of the TB muscles decreased during the CPR trials, other muscles needed to increase force output to maintain the same level of chest compression force; the PM appeared to increase its contribution of force for chest compressions to compensate for the decrease in force output from the TB muscles. Trowbridge et al. (2009) found a significant decrease (p<.001) in PM activation over the course of ten minutes of CPR, whereas the current study found a significant increase in PM activation over the two minute CPR trials. Trowbridge et al. contributed this decrease in PM force output to a selective mechanism to reduce overall fatigue. The different results between Trowbridge et al. and the current study may be due to the length of CPR administration, as no differences were found in muscle activation between CPR types, consistent in both studies.

It is interesting to note that of all the muscles measured in this study, the TB displayed the highest normalized activation, as high as 32% MVC at the onset of CPR administration, which may suggest that this muscle is most likely to become fatigued over time. The TB being a relatively smaller muscle group may not have the ability to recruit as readily as the erector spinae muscle group does (Monti, Roy, & Edgerton, 2001). Aside from muscle recruitment, the other mechanism to maintain equal force output is to increase muscle firing rate (De Luca, 1985). If the muscle is not able to increase its firing rate to compensate for its lack of recruitment, a closely related muscle may need to increase its activation to compensate for this decrease in muscle activation. In this case, the PM muscle activation may have increased to compensate for the decreasing TB muscle activation.

In many cases, increased muscle activation may be an indication of muscle fatigue, but other factors such as coactivation of two or more muscles to complete a certain task, may play a role in the level of muscle activation for a given muscle, especially during a dynamic task. It is likely that a combination of trunk and upper extremity muscle activation must occur to effectively perform CPR and that the individual contribution of each muscle changes as these muscles fatigue.

5.3.3 An Explanation for the Initial Drop in Chest Compression Force during cont-CPR

As described above, the initial drop in chest compression force during cont-CPR and a force plateau for the first 40 seconds in standard CPR is worth further investigation. The lack of differences between muscle activity and lumbar spine posture between the two CPR types does not help to explain this difference in chest compression force. However, a closer examination of muscle activation revealed a gradual decrease in TB activation during only the cont-CPR trials (figure 16), while during the standard CPR trials activation remained steady. This may indicate decreased force output by the TB muscles and thus decreased chest compression force during cont-CPR. However, what was even more interesting was that even in the first 20 seconds, there was still a steady decline in force during the cont-CPR trials. During the first 20 seconds, the actual administration of CPR was not different between the two types. The participants may have adjusted their force application in anticipation of having to continually perform chest compressions for a full two minutes without a break. Anticipatory effects of higher perceived exhaustive activities have been shown to highly correlate with measurable fatigue (Hogan & Fleishman, 1979; Mital et al., 1994). Further, the actual rate of force decline following the first 40 seconds (at which point force began to decline during standard CPR trials) was similar between the two CPR types (0.48N/sec during standard CPR and 0.58N/sec during cont-CPR). It is possible that the initial decline was also a psychophysical response to performing cont-CPR. Previous studies have shown that individuals are able to perceive safe lifting loads and rates depending on how long they are required to perform the task (Ciriello, Snook, Blick & Wilkinson, 1990; Snook, 1978; Snook and Ciriello, 1991). However, if this were the case, it would have been hypothesized that the chest compression force at the start of the trials would have been lower during cont-CPR compared to standard CPR, which was not the case. At the start of CPR administration, force application was approximately 600N for both types and therefore it did not appear that participants "paced themselves", with regards to the amount of chest compression force, right from the start during the cont-CPR trials.

5.4 Considerations

There are a number of points that should be considered in the current study. First, due to difficulty recruiting and time constraints within the scope of this project, the target sample size of emergency responders could not be reached. However, the amended participant pool allowed for a broader spectrum of individuals who may have to perform CPR in their lives.

Second, with the motion capture system used in this study being electromagnetic, it is very sensitive to surrounding metal, so any metal in the laboratory reduced the range of motion detection. This effect was reduced as much as possible by manufacturing a custom stand for the electromagnetic source, which was composed of a plastic base filled with sand, holding a wooden pole in place where the source was mounted using nylon screws. Given the nature of CPR being performed in a single location with no locomotion, this was not a significant problem to circumvent for recording lumbar spine flexion/extension in this study.

Third, to keep the performance of CPR relatively similar with regards to rate of chest compressions, between participants, the use of a metronome was set at 100 beats per minute for each participant during all the CPR trials. Although there were times when some participants slightly deviated from the pace, they were able to quickly regain the target rate of chest compressions. This was controlled for in the analysis, as much as possible, by breaking down CPR data by time points measured in seconds, instead of measuring time points by number of chest compressions.

With consideration of the limitations present in this study, the results still provide critical and important information and provide insight into the performance of CPR among emergency responders and civilians.

5.5 Future Directions and Recommendations

5.5.1 Future Directions

This study was the first of its' kind exploring the biomechanics of performing CPR under realistic performance conditions, with respect to the timing of performing the procedure. Though CPR is performed in many different environments under different conditions, it is important to investigate rescuer biomechanics in a controlled setting to gain insight into the basic biomechanics before applying it to situations in the field.

Due to a likely switch in AHA recommended standard CPR from 30:2 to cont-CPR it was important to investigate the biomechanical effects of both CPR types. Though there was no main effect of CPR type for all measures, there was in interaction when analysing chest compression force, displaying a significant difference in chest compression force decline over time between standard CPR and cont-CPR. This may be the result of fatigue to muscles that were not analysed in a manner to determine this. In particular, due to the substantial involvement of the TB muscle, future work should consider examining fatigue of this muscle during CPR. In addition, the greater drop in chest compression force during cont-CPR may be an anticipatory response particularly because a drop in force was observed even after 20 seconds during which cont-CPR was exactly the same as standard CPR. It would be interesting and valuable to examine the psychophysical nature of performing both cont-CPR and standard CPR.

The next step after this project may be to investigate how various environments requiring different postures affect the performance of CPR. For instance, when emergency responders have to perform CPR in an ambulance, they may have to brace themselves with one hand, leaving them with just a single arm to perform chest compressions. This would affect not only the biomechanics greatly, but would likely affect chest compression force output and asymmetrical muscular fatigue.

Last, it may also be beneficial to survey a large population of emergency responders to include individuals with LBP as well as non-LBP reporters to investigate how the presence of LBP may affect the performance of CPR.

5.5.2 Recommendations

Fatigue has been associated with decreased motor control and increased risk of injury in an occupational setting (Johnston, Howard, Cawley, & Losse, 1998; Swaen, van Amelsvoort, Bultmann, & Kant, 2003). Due to the large drop in chest compression force while performing cont-CPR observed in this study, for the emergency responder population, it is recommended that the duration of CPR administration in a multi-person rescue be reduced from two minutes to one or one and a half minutes to help reduce the risk of fatigue and potential injury to the rescuer. With regards to the cardiac arrest victim, visual feedback during the administration of OHCA CPR may decrease the high magnitude of chest compression force, while maintaining sufficient chest compression depth, in order to decrease the chance of unnecessarily damaging the victim’s internal organs. This study displayed that civilians were not able to perform sufficient chest compression force with regards to the current AHA guidelines during neither standard CPR nor cont-CPR, where the rate of decline between the two conditions did not appear to be very different (0.37 N/sec for standard CPR, and 0.48 N/sec during cont-CPR). Therefore the current AHA recommendations of performing cont-CPR “faster and harder” may increase survival rates for cardiac arrest victims and may not differ significantly between conditions with regards to rescuer fatigue.

There are a number of mechanical chest compression devices that have been designed, all of which claim to perform “perfect” uninterrupted chest compressions, while being able to accommodate many different chest properties. One particular model (Zoll AutoPulse®) has been shown to increase survival rates in OHCAs to 9.7%, when compared to manually applied chest compressions, at 2.9% (Ong et al., 2006). The use of this technology removes rescuer fatigue from affecting the quality of chest compressions, but requires manual adjustments to account for the differences between individual’s chest properties. Further, these devices are very expensive and may not be realistic for many settings. Additional investigation into the use of these devices may be warranted to weigh the pros against the cons to determine how realistic it is to implement these into the emergency services, as they require training to operate.

6.0 Conclusion

With regards to chest compression force over time regardless of CPR type, two-minutes of CPR appeared to be fatiguing to the point where most individuals were not able to perform effective chest compressions by the end of the two-minute trials. However, when emergency responders and civilians were separated, it was clear that almost all civilians were not able to maintain sufficient chest compression force for effective CPR throughout the two minutes, whereas most emergency responders were able to perform effective compressions through the two-minute CPR trials. Many emergency responders exceeded the recommended force to compress the chest to a sufficient depth, which may cause the greater chest compression force decline observed in the emergency responders during cont-CPR.

With regards to muscle activation, LES muscle activation was found to increase over time, suggesting the low back musculature needed to increase force output to sustain proper low back posture to perform CPR. A shift in upper extremity muscle activation was observed as there was an increase in PM muscle activation while TB muscle activation decreased. The decrease in TB activation may have been the driving force behind the increase in PM activation, as a compensation mechanism in order to sustain the same degree of chest compression force. After analysing the frequency content of the LES, no muscle fatigue was found suggesting that the performance of CPR, at least for only two minutes, does not elicit low back muscular fatigue. Though no low back muscular fatigue was found, evidence that suggests cardiovascular fatigue developed. All variables measured in the RPD scales as well as the RPE scores were found to significantly increase post-CPR trials, compared to pre-CPR trials. The increased RPE and RPD scores and decreased chest compression force over time convey the exhausting nature of performing CPR.

In conclusion, CPR is a very exhaustive procedure to perform effectively regardless of whether an individual is performing cont-CPR or the current AHA standard CPR. However this study showed that it was much more difficult to sustain sufficient chest compression force for effective CPR when performing cont-CPR compared to standard CPR. If a switch in AHA standard (30:2) to cont-CPR occurs, amendments to the procedure with regards to length of time performing CPR (one or one and a half minute cycles vs the current two minute cycles) may be necessary to reduce risk of injury for the individuals performing the procedure, as well as affording these individuals the ability to perform efficient CPR the entire length of time without tiring. Further, the performance of cont-CPR may only be a good idea for emergency responders as civilians were not able to perform effective CPR for the entire two minute trials. This ergonomic analysis of performing CPR revealed that cont-CPR may be too exhausting to perform for two continuous minutes, which may decrease the effectiveness of CPR and increase risk of injury for the individual performing CPR.

7.0 References

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Appendix A: Apparatus

Figure A1. Aerial view of the force transducer encompassed in the metal casing, next to a 30 cm ruler.

Appendix B: Questionnaire

B1. Firefighter Questionnaire

1. What is your gender (please circle)? Male Female
2. Are you a smoker (please circle)? Yes No
3. What is your height (feet/inches)? ______
4. What is your weight (pounds)? _______
5. What is your age? _______
6. How often do you participate in moderate-to-vigorous physical activity per week, lasting 30 minutes or more? (Please circle one)
    a. 1 day/week
    b. 2-4 days/week
    c. 5 days/week
    d. 6-7 days/week
7. How many years have you been a firefighter (If less than a year, how many months)? ________
8. Are you employed part-time or full-time as a firefighter (please circle one)?

PT FT

9. How many services do you work for (please circle one)?
    a. 1
    b. 2
    c. 3+
10. On average, how often do you have to perform CPR during a month, while on the job? (please circle one)
    a. 0-3
    b. 4-6
    c. 6-10
    d. 10+
11. How many other emergency responders are usually with you while you perform CPR? ________
12. When performing CPR:

1. On average, how long does a cycle of CPR last before switching out with another rescuer? (please circle one)
    a. 0-30 seconds
    b. 30 sec. to 1 minute
    c. 1-2 minutes
    d. 2+ minutes

2. On average, how many cycles of CPR do you have to perform on one patient? (please circle one)
    a. 1-5 cycles
    b. 5-10 cycles
    c. 10-15 cycles
    d. 15+ cycles

13. Where do you perform CPR most often as a first responder? (please circle one, or indicate other location)
    a. On the floor/ground
    b. On a stretcher
    c. In an ambulance
    d. Other: ___________________

14. Do you have a history of Low Back Pain (LBP) (please circle one)?

Yes No

(If "Yes" please answer the following questions):

a. How long ago was the onset of LBP (if less than a year, please indicate number of months)?
______

b. To your own knowledge, did a specific event or injury result in your LBP? (please circle one)
Yes No

c. Did your LBP start before or after you became a firefighter? (please circle one)
Before After

d. If LPB has occurred after you became a firefighter, do you believe performing CPR has exacerbated the injury? (please circle one)
Yes No

e. Do you believe that CPR caused your LBP? (please circle one)
Yes No

15. Do you experience pain in any of the following areas (please circle all that apply and indicate "right", "left", or both sides of your body on the line provided):
    a. Shoulder __________

    b. Wrist _____________

    c. Elbow ____________

    d. Hip _______________

    e. Knee _____________

16. If you experience pain to any of the above areas, please answer the following questions:
    1) Do you believe CPR has been a significant contributor to the pain? (please circle one)
       Yes No

    2) Does performing CPR exacerbate the injury? (please circle one)
       Yes No

17. On a scale of 0-10, 0 being no pain and 10 being worst imaginable pain, rate your perceived level of low back pain:
    (please respond on the line provided)

    1) Current LBP: ______

    2) LBP at its worst: ______

    3) Average LBP: ______

B2. Non-Firefighter Questionnaire

1. What is your gender (please circle)? Male Female

2. Are you a smoker (please circle)? Yes No

3. What is your height (feet/inches)? ______

4. What is your weight (pounds)? _______

5. What is your age? _______

6. How often do you participate in moderate-to-vigorous physical activity per week, lasting 30 minutes or more? (Please circle one)
   - e. 1 day/week
   - f. 2-4 days/week
   - g. 5 days/week
   - h. 6-7 days/week

7. How many years have you had continuous CPR certification? (If less than a year, how many months)? ________

8. On average, how often do you have to perform CPR during a month?
   - a. 0-3
   - b. 4-6
   - c. 6-10
   - d. 10+
   - e. Not applicable

9. How many other emergency responders are usually with you while you perform CPR? ________ If not applicable, circle: N/A

10. When performing CPR:

    1. On average, how long does a cycle of CPR last before switching out with another rescuer? (please circle one)

       - a. 0-30 seconds
       - b. 30 sec. to 1 minute
       - c. 1-2 minutes
       - d. 2+ minutes
       - e. N/A

    2. On average, how many cycles of CPR do you have to perform on one victim? (please circle one)
       - e. 1-5 cycles

    f. 5-10 cycles
    g. 10-15 cycles
    h. 15+ cycles
    i. N/A

11. Where do you perform CPR most often? (please circle one, or indicate other location)
    e. On the floor/ground
    f. On a stretcher
    g. In an ambulance
    h. Other: _________________
    i. N/A

12. Do you have a history of Low Back Pain (LBP) (please circle one)?

    Yes No

    (If "Yes" please answer the following questions):

    f. How long ago was the onset of LBP (if less than a year, please indicate number of months)?
    ______
    g. To your own knowledge, did a specific event or injury result in your LBP? (please circle one)
    Yes No N/A

    h. Do you believe performing CPR has exacerbated the injury? (please circle one)
    Yes No N/A

    i. Do you believe that CPR caused your LBP? (please circle one)
    Yes No N/A

13. Do you experience pain in any of the following areas (please circle all that apply and indicate "right", "left", or both sides of your body on the line provided):
    a. Shoulder __________

    b. Wrist _____________

    c. Elbow ____________

    d. Hip _______________

    e. Knee _____________

14. If you experience pain to any of the above areas, please answer the following questions:

    1. Do you believe CPR has been a significant contributor to the pain? (please circle one)

    Yes No N/A

2. Does performing CPR exacerbate the injury? (please circle one)
   Yes No N/A

15. On a scale of 0-10, 0 being no pain and 10 being worst imaginable pain, rate your perceived level of low back pain:
    (please respond on the line provided)

4) Current LBP: ______

5) LBP at its worst: ______

6) Average LBP: ______

Appendix C: ROM and MVCs

MVC trial

Figure C1. Illustration of the back MVC. The participant extended their back to horizontal and parallel to the ground, and a maximum back extension was resisted by the experimenter.

Figure C2. Illustration of the triceps brachii MVC. The participant held their upper arm at neutral position with elbow flexed 90 degrees and extended with maximal force against the experimenters resistance.

Figure C3. Illustration of the pectoralis major MVC. The participant maximally adducted their upper arms against the resistance of a cabinet.

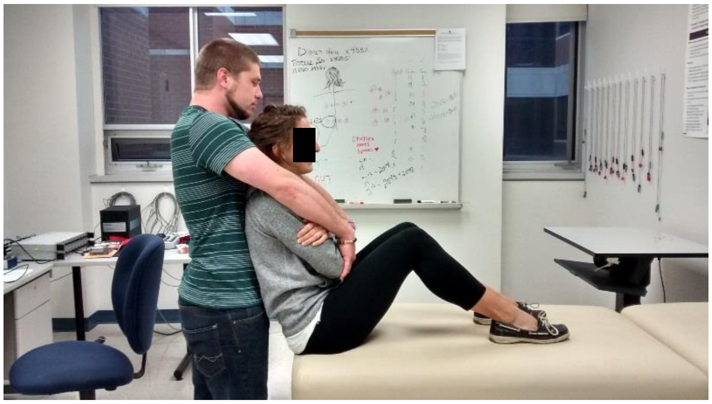

Figure C4. Illustration of the abdominal musculature MVC. The participant performed three maneuvers, two of which were bilateral, against the resistance of the experimenter.

ROM: Flexion/ Extension

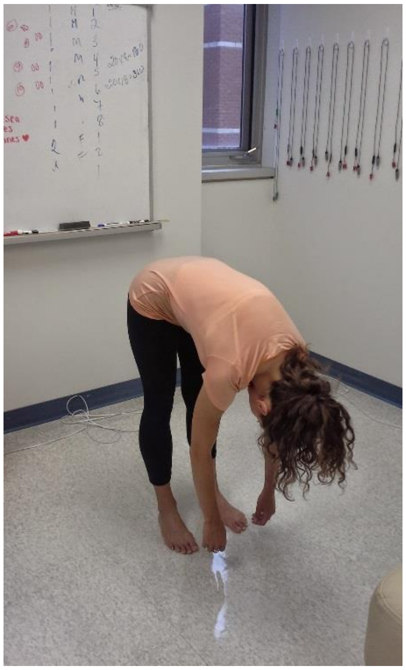

Figure C5. Participant performed full trunk flexion ROM trial.

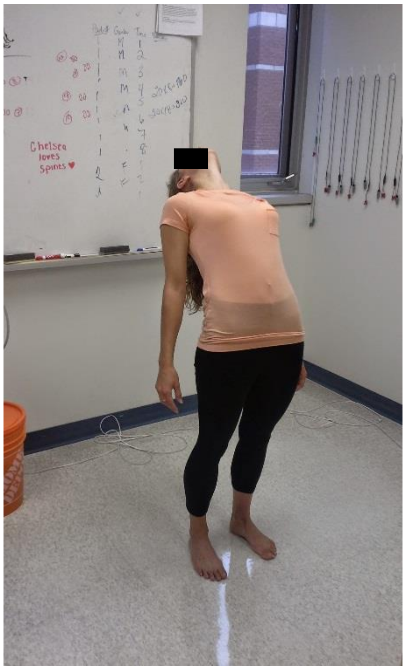

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Figure C6. Participant performed full trunk extension ROM trial.

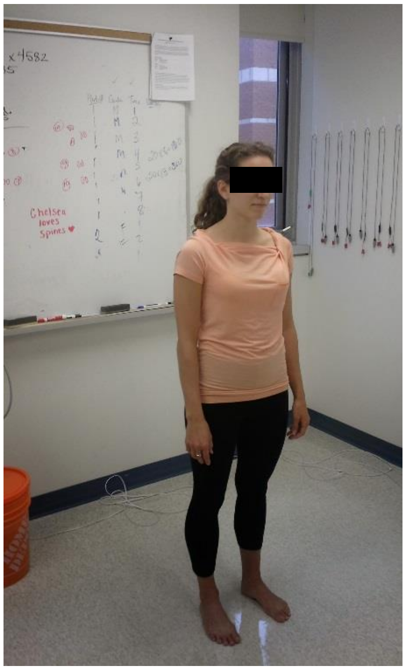

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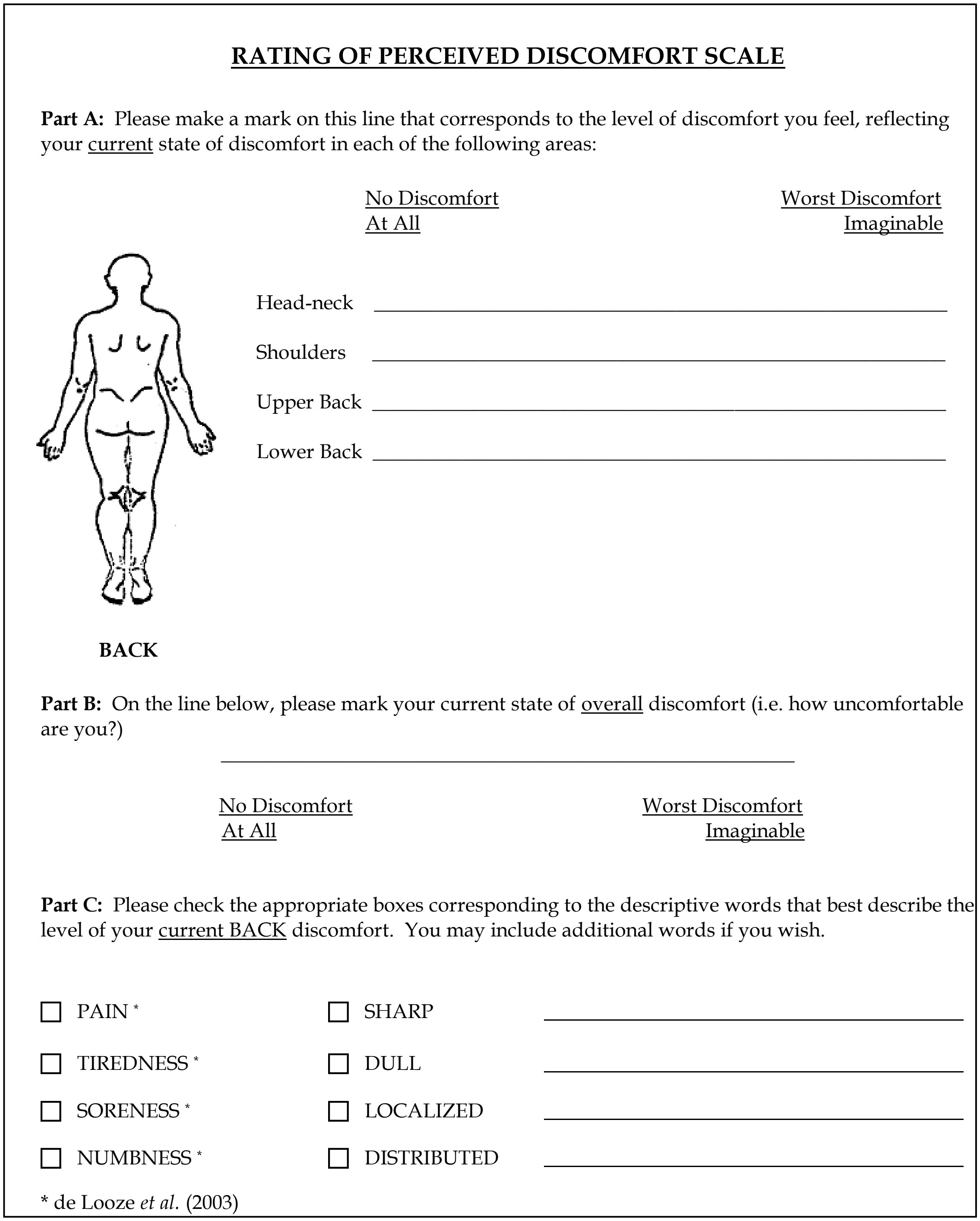
Figure C7. Participant performed quiet neutral standing trial.

Appendix D: Perception Rating Scales



RATING OF PERCEIVED DISCOMFORT SCALE

Part A: Please make a mark on this line that corresponds to the level of discomfort you feel, reflecting your current state of discomfort in each of the following areas:

No Discomfort At All — Worst Discomfort Imaginable

Head-neck ____________________

Shoulders ____________________

Upper Back ____________________

Lower Back ____________________

BACK

Part B: On the line below, please mark your current state of overall discomfort (i.e. how uncomfortable are you?)

____

No Discomfort At All — Worst Discomfort Imaginable

Part C: Please check the appropriate boxes corresponding to the descriptive words that best describe the level of your current BACK discomfort. You may include additional words if you wish.

☐ PAIN *	☐ SHARP	____________________
☐ TIREDNESS *	☐ DULL	____________________
☐ SORENESS *	☐ LOCALIZED	____________________
☐ NUMBNESS *	☐ DISTRIBUTED	____________________

* de Looze *et al.* (2003)

Figure D1. Rating of perceived discomfort (RPD) scale administered at each time point the Biering Sorensen back extensor fatigue test was performed.

Rating of Perceived Exertion (RPE)

6	No exertion at all
7	
	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Vey hard
18	
19	Extremely hard
20	Maximal exertion

Figure D2. Rating of perceived exertion (RPE) scale administered at each time point the Biering Sorensen back extensor fatigue test was performed.

Appendix E: Muscle activation over time during only the cont-CPR trials.

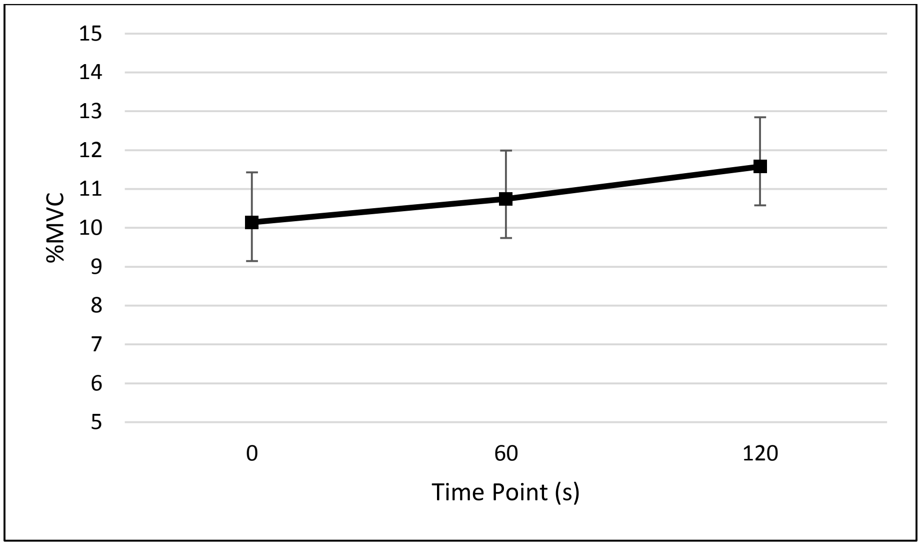


Figure E1. Left LES mean muscle activation during cont-CPR only.

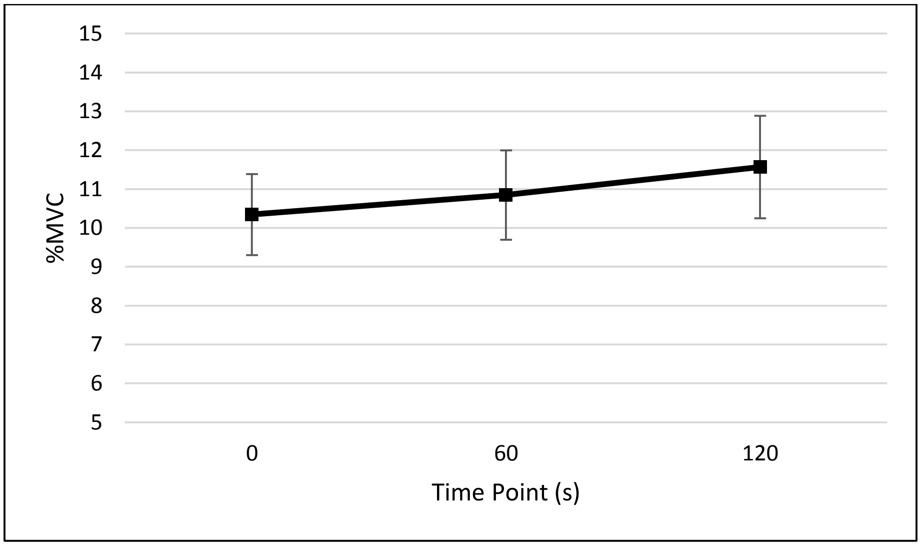


Figure E2. Right LES mean muscle activation during cont-CPR only.

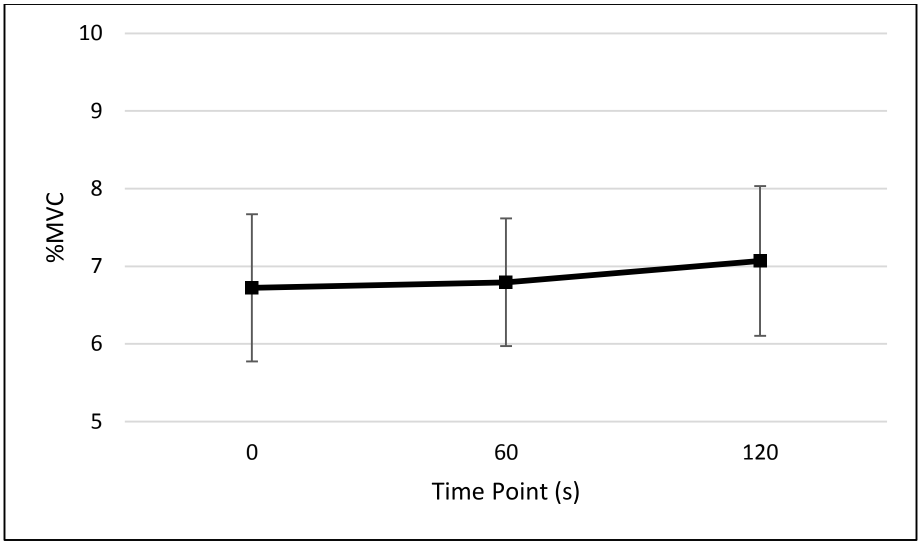


Figure E3. Left TES mean muscle activation during cont-CPR only.

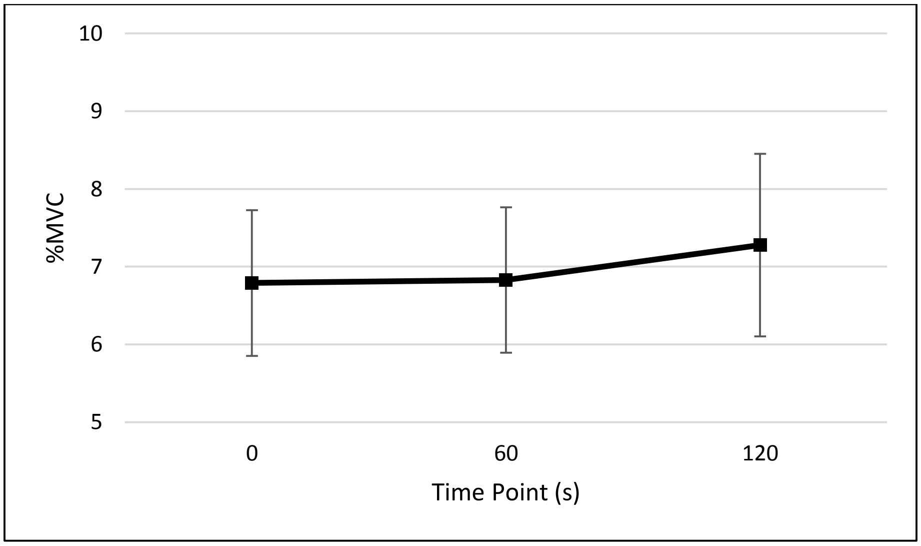


Figure E4. Right TES mean muscle activation during cont-CPR only.

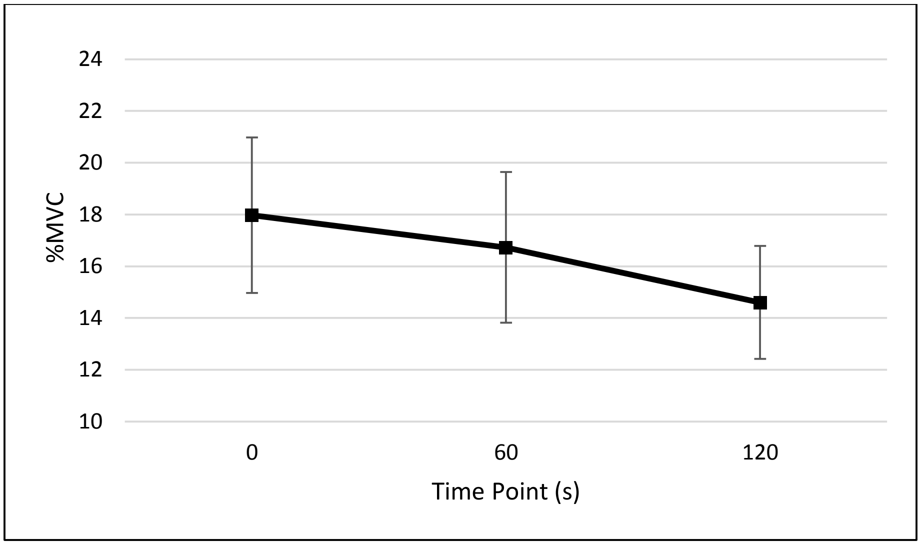


Figure E5. Left RA mean muscle activation during cont-CPR only.

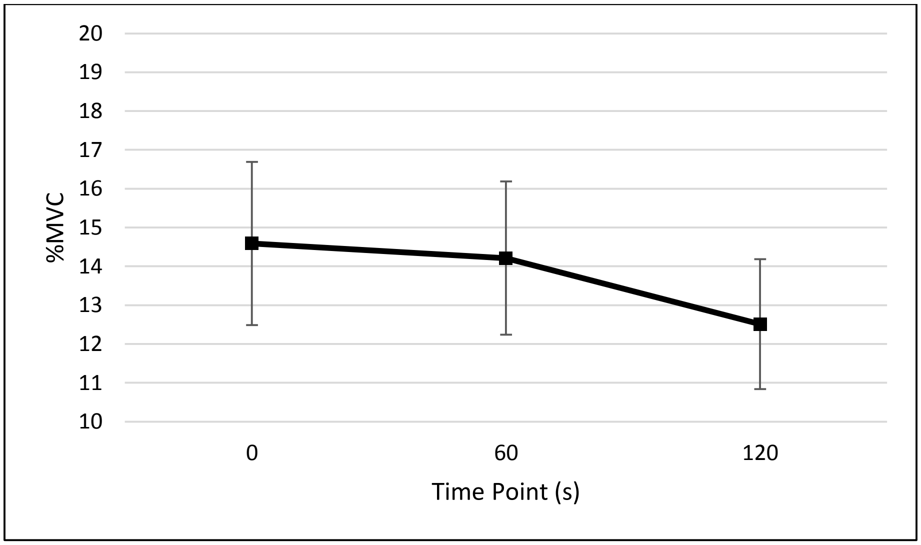


Figure E6. Right RA mean muscle activation during cont-CPR only.

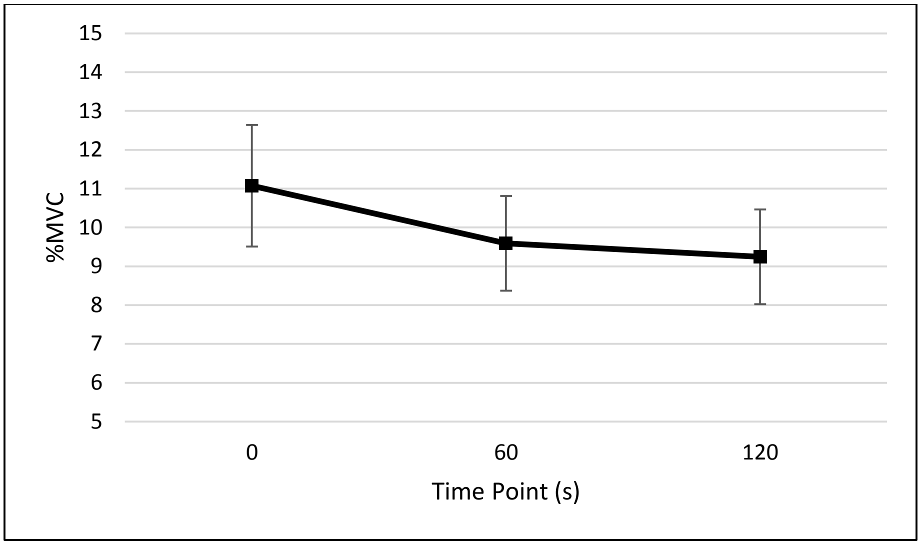


Figure E7. Left EO mean muscle activation during cont-CPR only.

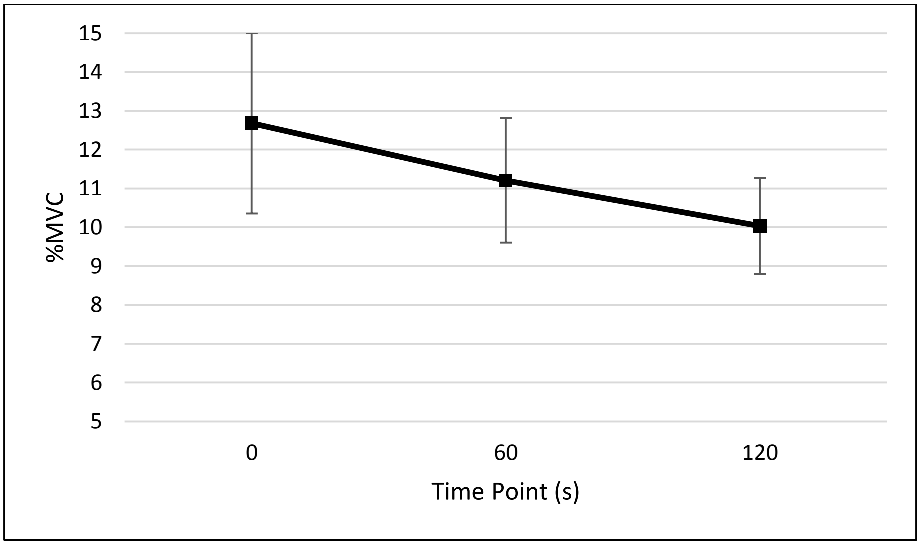


Figure E8. Right EO mean muscle activation during cont-CPR only.

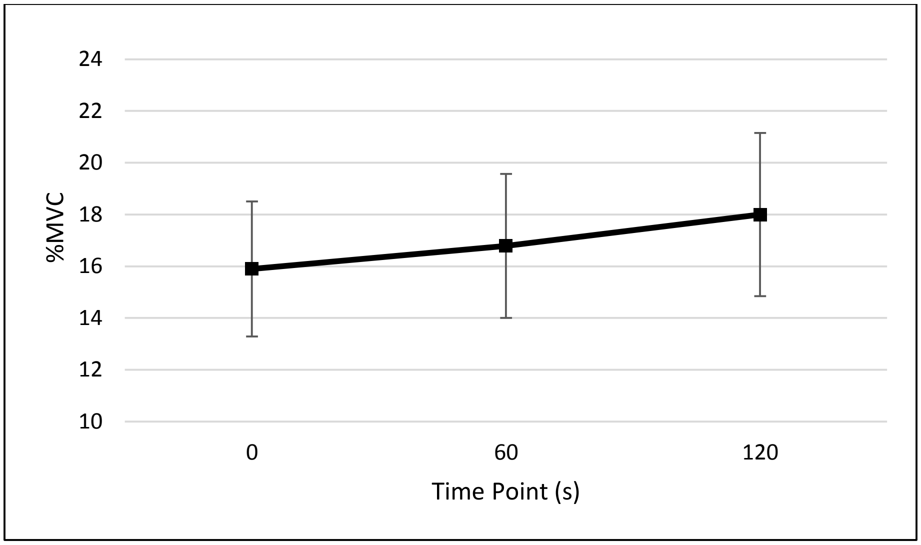


Figure E9. Left PM mean muscle activation during cont-CPR only.

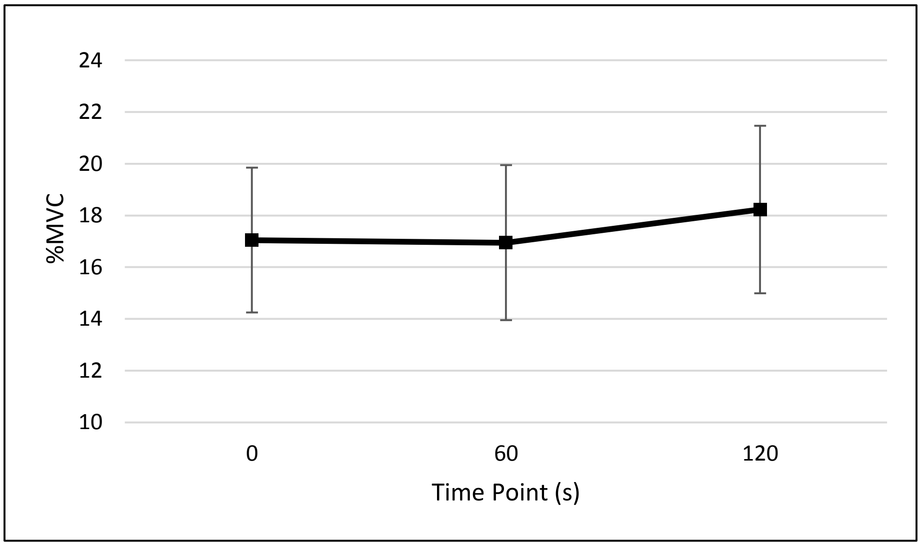


Figure E10. Right PM mean muscle activation during cont-CPR only.

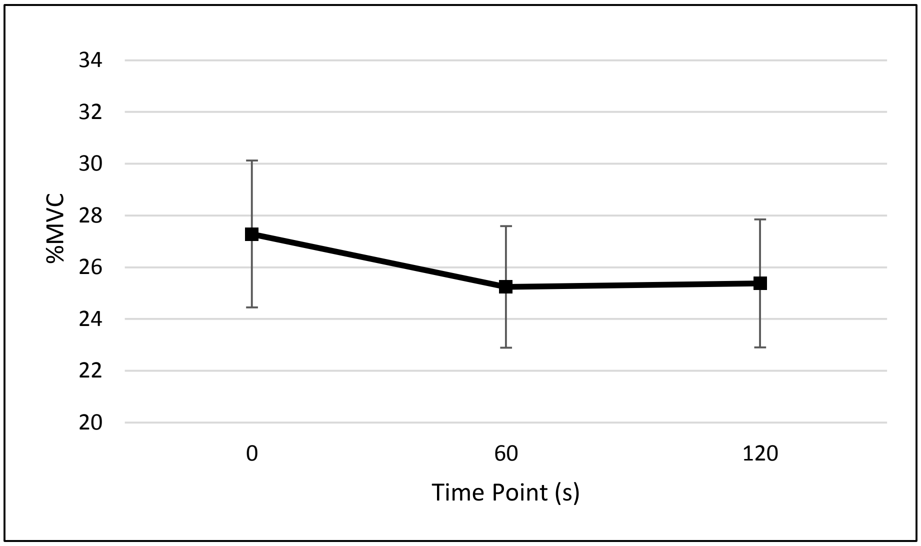


Figure E11. Right TB mean muscle activation during cont-CPR only.