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The Effect of Weighted Body Armor on Close Combat Reaction Time and Core Muscle Activation

by

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ABSTRACT

The purpose of this study was to measure the choice reaction time and myoelectric activity of the right and left rectus abdominus, and right and left external obliques required to initiate movement in response to a visual stimulus that signaled performance of four different close-combat movements (left or right cross and left or right dodge). Reaction time and myoelectric activity were then compared with performing the movements in response to the visual stimulus while wearing a weighted vest that simulated wearing tactical body armor. Myoelectric activity was measured as the average root mean square (RMS) of the surface electromyography (sEMG) values. The hypotheses were that average time to react to the visual stimulus for each movement and average myoelectric activity to initiate the movement would be greater under the weighted vest condition. The participants were 10 active martial arts/boxing performers from different disciplines with a minimum one year experience in their discipline. During two separate sessions, the participants completed eight warm-up trials and 24 measured trials, with the first four trials deleted. The stimuli were activated in a random order with foreperiods ranging from 10 to 20 seconds between trials. The sessions were randomly chosen to be either loaded or unloaded conditions. Surface EMG electrodes detected the myoelectric activity of the right and left rectus abdominus, and right and left external oblique muscles. The electrodes pre-amplified the myoelectric signals by a factor of 35. The sEMG signals of the four muscles were treated with a 20 Hz low cut/high pass filter, amplified by a factor of 20,000, and the RMS of the filtered signals were derived using an 11.75 ms time window. The analog RMS sEMG was sampled at 1020 Hz and converted to digital form. The reaction time for each movement was determined from the initiation of the stimulus to the point at which myoelectric activity reached the threshold of 0.5 volts. A two-tailed paired samples t-test was run to determine differences between the average reaction time and average RMS sEMG for each core muscle during each movement for the unweighted and weighted conditions. A one-way ANOVA with repeated measures was run to determine significant differences in average reaction time and average total muscle activity between the unweighted and weighted conditions for the group. Alpha was set at 0.05. Significant differences were found between the unweighted and weighted conditions for reaction time while performing the left dodge, right cross, and right dodge with slight significance for the left cross ($p = 0.047$, $p = 0.014$, $p = 0.002$, and $p = 0.059$, respectively). Further, group average reaction time was significantly greater in the weighted condition ($p = 0.001$). No significant differences were found in initial muscle activity between the conditions. These results support the first hypothesis that mean reaction time would significantly increase when performing close-quarters combat movements in response to a visual stimulus while wearing a loaded vest. Combatives instructors, specifically military and law enforcement, can use this information as a means to further protect the armed forces by training them in the protective gear that they will be wearing out in the field. This will hopefully acclimatize the armed forces to a point where performance will not hinder to complete missions in hostile environments.

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

TABLES

FIGURES

CHAPTER 1

INTRODUCTION

Law enforcement and military personal face unexpected scenarios on a regular basis. Their ability to react to dangerous situations can be the difference between life and death for themselves and their teammates. Martial arts and self-defense skills have been implemented in the training of law enforcement and military personal as a tool to provide quick and brutal force as a means to disarm or incapacitate a culprit. These skills are also used to defend against close-combat attackers.

Through the past 100 years, arms technology has grown. The use of this technology by criminals and military enemies has grown, as well. It has led to an increase in what has been called unconventional warfare (Grdovic, 2009), where engagements occur at longer distances and sporadic conditions due to the lethality of the weapons used. Unconventional warfare also means that there is no specific battle ground or front. In more recent years, the setting for unconventional warfare has been urban. Military and law enforcement operations that involve clearing buildings, searching subjects, and driving through hostile areas with unknown enemy positions have led to greater chances of close quarters combat.

Military and law enforcement offices have developed protective equipment in an attempt to reduce casualties, but allow their men and women to continue carrying out their duties. One of these pieces of equipment is the interceptor body armor, or more commonly called, bullet proof vest. The function of the vest is to reduce or eliminate injuries to the thoracic region from bullets, shrapnel, and puncturing weapons. As the lethality and brutality of weapons and confrontation techniques used by suspects have evolved, body armor material and designs have also evolved.

The increased load produced by body armor has been previously studied for its effect on aerobic and anaerobic systems during combat simulated exercises. There have also been studies on how the increased load affects aerobic, anaerobic, and motor performance. The current literature is limited in the study the effects of load carriage on close-quarters combative movements during a simulated scenario to respond to an assailant; an essential ability for military and law enforcement carry out missions and survive sudden hostile attacks. The ability to react to a culprit who is within arms-length striking distance may be the difference between life and death.

Statement of the Problem

An increase in protective equipment may affect the ability to respond to hostile movements with potentially fatal consequences. The purpose of this study was to investigate the effects of wearing a weighted vest on reaction time. Further, this study also investigated the effects of wearing a weighted vest on core muscle activation. Reaction time and myoelectric activity was measured using surface electromyography (sEMG).

Significance of the Study

The results of this investigation can provide trainers in all tactical professions further understanding of how body armor affects performance, and the importance of consistent training while wearing protective equipment for all combat scenarios.

Hypothesis

The first hypothesis of the study is that wearing the weighted vest will significantly increase choice reaction time. The second hypothesis is that wearing the weighted vest will significantly increase sEMG core muscle activity to initiate the movement and result in an interaction with the increased reaction time.

Limitations

The limited research on this topic has used more recently produced EMG measuring equipment. The EMG, electrodes, and conducting gel that was used during this study were produced in 1989. Another limitation is that the study was conducted in a non-hostile, controlled environment. This controlled environment was inconsistent with the hostile environment where military and law enforcement conduct missions. Hidden variables, such as adrenaline response and visual distractions, were not measured and may or may not have factored into the results.

Delimitations

The subjects will have at least 6 months of combatives experience. The time between trials was a combination of time duration for the software to save the data and foreperiod chosen by the researcher. The reaction time of the movement and myoelectric activity was measured for the right and left rectus abdominis, and the right and left external obliques. Fatigue for the subjects was subjective and not measured, so fatigue was not taken into account for the results.

Assumptions

It was assumed that the procedures used to measure reaction time and myoelectric activity will be valid and reliable. It was also assumed that gender will not affect the results and that all participants will have enough martial arts or boxing experience to perform the same movements consistently for each trial, and that the technique will be similar no matter which striking discipline is the background for each participant. The end of the reaction time interval was assumed to occur when the sEMG RMS for one of the muscles reached 0.5 V.

Definition of Terms

Combatives. The general term used by the US Army to describe the combination of martial arts techniques used defend, disarm, and incapacitate during a close encounter with an attacker.

Cross. A straight punch where a slight twisting motion of the abdominals occurs so greater force is generated and the hand ends up parallel with the puncher's midline when it strikes the target.

Dodge. A trunk lateral flexion movement that moves the thorax and head in unison to avoid a strike from an opponent.

Electromyography (EMG). A technique for evaluating and recording the myoelectrical activity of muscles. An electromyograph detects the electrical potential generated by muscle cells when these cells contract or are at rest. The muscle activation in this study will indicate when reaction time ends and response time begins.

Forward guard position. The standing, fight-ready position in which the individual stands with feet shoulder width apart, hips and shoulders square to the target, hands up at eye level, elbows flexed at slightly above 90°, and neck slightly flexed so the chin is behind the hands.

Foreperiod. The time period between the end of a movement and the initiation of a stimulus to prompt another movement.

Load Carriage. The external load that usually consists of military and other tactical equipment that may be worn (body armor, belt, vest, etc.) or carried (backpack, double pack, etc.).

Reaction time. The period of time between the initiation of the visual stimulus and the point at which the sEMG activity of one of the core muscles reached 0.5 V, indicating the beginning of the response.

Root mean square. A method for quantifying sEMG in which each sEMG value is first squared, then the squared sEMG values over a specified time interval are averaged, and finally the square root of the average is computed as the root mean square value (RMS). "The RMS reflects the mean power of the signal (also called RMS EMG) and is the preferred recommendation for smoothing" (Konrad p. 11, 2006).

CHAPTER 2

REVIEW OF LITERATURE

As unconventional warfare becomes more prominent, the use of body armor to protect armed forces and law enforcement officers has become a critical component their protective equipment. Although most engagements for armed forces occur at long distances, the Washington Post (2007) reported that improvised explosive devices (IED) were responsible for 60% of coalition force casualties that occurred during Operation Iraqi Freedom from 2003 – 2007. IEDs are camouflaged in the ground and triggered by enemy radicals when soldiers are in close enough proximity to the blast zone. Military and law enforcement forces participate in missions that require clearing rooms with limited visibility and an increasing chance of encountering enemies or suspects in close proximity (United States Army Combatives School, 1995; Muszynski, 2004). These combat situations require that body armor be strong enough to protect soldiers and police, but also nonrestrictive for quick movements in close combat situations.

The physical characteristics of body armor have changed over the years in response to the sophistication and lethality of enemy combatants. Many of the studies discussed in this review have reported various physiological and performance effects of wearing loads on the ability to perform tasks related to military and law enforcement personnel. Many of the tasks were non-combative in nature: ruck marches, running, load carrying for distance, sprinting, agility, muscle endurance, tactical movements, and marksmanship. Furthermore, to this researcher's knowledge, much of the research involving martial arts and hand-to-hand combatives have investigated physiological and motor performance effects of different styles without the inclusion of increased loads. Since most martial arts and combatives do not require weighted protective equipment usage during training, the use of such equipment may be detrimental to performance when worn during missions. The purpose of this literature review is to provide a brief history of body armor usage, overview of prior investigations of load carriage effects on physiological and cognitive systems during performance, the effects of load on performance, overview of prior investigations of physiological and cognitive systems involved in combatives, discussion of physiological variables involved in combatives, and a proposed solution to address gaps in the literature regarding combatives performance under load carriage conditions.

Brief History of Body Armor

Evolution and use of body armor. The use of body armor for combat can be traced back to animal hides used by cavemen (Muszynski, 2004), but the first body armor developed to actually stop penetration from weapons was made of iron by the Assyrians (Gabriel, 2002) in the 7th century BC. This metal armor evolved into the development of a full iron body dress (panoply) created by the ancient Greek Hoplites. This style of armor eventually proved ineffective for the Hoplite soldier, since the armor's weight, 33 – 47 per cent of the soldier's body mass, made the Hoplite soldiers vulnerable to faster moving enemies. The Spartans and Macedonians determined that success in battle was affected by movement. As such, bronze armor was form-fitted to protect the head, thoracic region, torso, and shins, but still weighed 22.5 kg (Orr, 2010).

This type of armor was adopted by the Romans and other European civilizations for centuries, until the early period of the Middle Ages when chainmail became primarily used for battle (Montross, 1960; Schreiner, 1997; & Orr, 2010). Chainmail was lighter (average of 16 kg), less restrictive, and allowed soldiers to mount and dismount; giving them the ability to either fight as cavalry or infantry. However, chainmail provided less protection as weapons and strategies changed and improved. Armies sacrificed the protection of their soldiers for more strategic mobility. In response to increasingly lethal weapons, plate armor was made to cover the vital body areas that chainmail could not fully protect. Unlike the Greeks and Romans, plate armor was made of steel and could be worn as just sections or a full suit (Di Liddo & Hewitt, 2009).

Soldiers continued to consistently wear heavy body armor until the introduction of firearms in the early 16th century. Muszynski (2004) found that Japanese Samurai developed a softer body armor made of silk. Di Liddo and Hewitt (2009), found that the Samurai reinforced the softer body armor with plate armor on the outside. The softer silk interior provided comfort and a molding mechanism to the body, so the plate armor could be more universal. However, production started to decline in use and construction due to the increase in expenditure for production of firearms. With the colonial expansion of the 16th – 18th centuries and the increased sophistication of firearms, body armor usage became scarcer as armies developed “light” infantry divisions in the wake of musket and cannon fire. In order to keep the infantry evasive, body armor became non-essential. By the 18th century, loads carried by light infantry soldiers started to progressively increase above 15 kg and body armor became too heavy, physically stressful, and restrictive (Knapik, Reynolds, & Harman, 2004).

As firearms and heavy weapons evolved, so did the idea of better protecting the military and law enforcement. Early experiments on proposed light weight body armor did not occur until the late 19th century. The concept of manufacturing bullet resistant armor using silk was reintroduced, however the armor proved ineffective against the firearms and ammunition of the time. After World War I, several new designs of body armor were introduced to the military and law enforcement offices (U.S. Dept. of Justice, 1998). The Washington D.C. police department first used the new body armor designs in 1931. There were no reports of effective use for the department. During World War II, heavy flak jackets were used to protect soldiers from shrapnel and other munitions fragments. They were still ineffective against direct gunfire or knife charges.

During the 1960's and 70's dramatic increases of law enforcement fatalities occurred in the United States. During the same period, many United States armed services personnel were killed in combat during the Vietnam War. In response, the National Institute of Law Enforcement and Criminal Justice and the U.S. Army began to conduct research on how to better protect officers and soldiers. The research resulted in Dupont's development of Kevlar®, a light weight, ballistic-resistant fiber (Muszynski, 2004). Successful test phases to resistance from ammunition and stabbing instruments were concluded by 1975 and mass production of Kevlar body armor started in 1976. This armor became common for personal protective equipment used by law enforcement and soldiers.

Modern day use. Different types of Kevlar vests have been made based on potential threat levels. The early Kevlar vets protected against .22 long rifle fire (Muszynski, 2004). Over the past 40 years, weapons continually evolved in sophistication and lethality, especially the use of improvised explosive devices (IED), automatic weapons, body piercing ammunition, and long range sniper rifles. This has led to the development of different classes of protective vests. Higher threat level missions and occupations with potential of encountering these weapons required the use of bulkier and heavier protective vests. Wars and enemy engagements have also changed from woods and open ground to urban areas with the increase of terrorist and guerilla tactics. Soft protective vests had to become stronger (harder metallic-like plates) and remain as lightweight as possible for tactical movements in restricted areas so soldiers and law enforcement could still carry out operations swiftly.

Belmont, Schoenfeld, and Goodman (2010) found that out of all reported injuries during Operation Iraqi Freedom, 5 – 7% were in the thoracic region that was protected by their body armor, and approximately 50% of all injuries were musculoskeletal. Larsen, Netto, and Aisbett (2011) reported that protective vests used in military operations range from 5.6 kg – 10 kg. Sell et al. (2010) further reported that the use of modern day tactical vests may be detrimental to combat movements and physical performance. Hooper (1999) also reported that police officers found their body armor restricted their ability to carry out tasks such as: running, jumping, entering and exiting the vehicle, and grappling with an assailant. However, the National Institute of Justice (2004) reported that protective vests were responsible for preventing 2,700 casualties from incidents involving gun shots and stabbings to the thoracic region.

Physiological Effects of Load Carriage/Body Armor during Combat Related Tasks

The weight of a protective vest is not the only extra load that military and law enforcement personnel must carry. Military and law enforcement personnel must also deal with an increase in total load carriage due to additional equipment they must carry while on duty. The effects of these load on performance and mobility will be reviewed in this section.

Metabolic effects. Cardiorespiratory endurance is the ability to take in and utilize oxygen during aerobic exercise (Caspersen, Powell, & Christenson, 1985). The capacity of cardiorespiratory endurance is measured when the highest rate of oxygen consumption is achieved during maximal exercise, known as VO_2 max. (Wilmore & Costill, 2004). VO_2 is an index of energy expenditure, so VO_2 is a common way to estimate energy expenditure (Quesada, Mengelkoch, Hale, & Simon, 2000). The increase loads carried by military and police have been of great concern for exercise scientists because of potential increases in energy expenditure that could lead to detriments in performance. Keren, Epstein, Magazanik, and Sohar (1981) reported that VO_2 increased by a rate of 0.6 (l/min)/(km/h) while walking and 0.3 (l/min)/(km/h) while running when carrying a 20 kg backpack load on a 5% gradient treadmill at increasing speed intervals: 6.4, 7.2, 8.0, 9.6, and 11.2 km/h. The rate of VO_2 increase was constant as speed increased, but aerobic capacity was significantly less at each speed when the load was carried (28.65, 33.78, 40.64, 46.84, 54.48 ml O2/kg BW/min, respectively, for the whole group without load vs. 26.52, 32.26, 38.28, 44.26, 48.16, respectively, with load, $p < .05$). Further analysis of the results found that the transition between walking and running occurred at a significantly lower speed for subjects with less mass. Therefore, if the load carried is a higher percent of the body mass, it may be a greater contributor to increased VO_2.

Patton, Kaszuba, Mello, and Reynolds (1991) had their subjects walk on a treadmill at three different speeds (1.10 m/s, 1.35 m/s, and 1.60m/s) carrying no load, 31.5 kg, and 49.4 kg for a fixed 12 km distance. Significant increases in VO_2 ranging from 10 – 18% occurred over time at the 2 faster speeds for 31.5 kg, and at all three speeds for 49.4 kg. VO_2 was found to be significantly higher for the 49.4 kg load at all three speeds than the

31.5 kg load. This study provided further evidence that VO_2 increases over time, but in contrast to Keren, Epstein, Magazanik, and Sohar (1981) not at a constant level.

Different factors can affect speed and magnitude of energy cost. Quesada, Mengelkoch, Hale, and Simon (2000) investigated variable load conditions based on body mass. The subjects performed three different 40 min walks at 6 km/h with no load, 15% of body mass, and 30% of body mass. $VO_{2,}$ and heart rate significantly differed for each condition throughout the marches. At the end of 40 minutes, relative energy costs for 0% of body weight, 15% of body weight, and 30% of body weight were on average 30, 36, and 41% of VO_2 max, respectively. Average heart rates were also significantly higher as the load carriage increased. However, the marches were performed at a 0% gradient on the treadmill.

Legg, Ramsey, and Knowles (1992) reported that placement of the load may have an effect on energy cost. Their subjects walked on a treadmill while carrying a 26 kg load as a backpack or asymmetrically strapped shoulder load on a treadmill. The subjects walked at a constant speed of 4.8 km/ h^{-1} with gradients of 0%, 2.5%, and 5%. After 5 minutes of walking it was found that heart rate and oxygen consumption were significantly higher for the shoulder carriage load for all three grades than the backpack carriage load (42·2-59·4% vs. 37.5-55.1 % V02 max). Knapik, et al. (1993), tested the effect of 34 kg, 48 kg, and 61 kg loads carried by each subject for six separate 20 km outdoor marches using the traditional ALICE pack (backpack) and an anterior/posterior (double) pack. Average heart rate was higher for each load throughout the march for the ALICE (All-Purpose Lightweight Carrying) pack (146 vs. 142 bpm). However, heart rate was significantly higher for the 34 kg load ($p < .01$). The results for heart rate from Knapik, et al. (1993) contrasted the results of Legg, Ramsey, and Knowles (1992) with regards VO_2 response to load carriage placement on the torso area. However, the subjects for the Knapik, et al. (1993) study walked at a self-choice pace while the Legg, Ramsey, and Knowles (1992) subjects were walking at a constant pace and grade for the complete duration.

Since load carriage usually consists of other tactical protective equipment, Legg and Mahanty (1985) investigated the energy expenditure and metabolic responses to different modes of load carriage consisting of 35% of body weight, including a tactical weight vest and different placement of packs on the subjects' body. All load carriages were reported to be similar in VO_2 and heart rate after walking for one hour on a 0% treadmill grade at 4.5 km/hr. Hasselquist et al. (2008) reported no significant increase in VO_2 ($p < .05$) between no body armor vest and body armor vest consisting of on average 19% of body weight when walking for 10 minutes at 1.34 m/s and running at 2.24 m/s. The inclusion of extremity armor increased VO_2 by 22 - 26% for walking and by 7% for running. The extra weight from the extremity armor increased the total load carriage on average 26% of body weight. In contrast, DeMaio et al. (2009) reported significant decreases in aerobic capacity ($48.3 + 5.7\ ml.min^{-1}.kg^{-1}$ to $42.9 + 4.9\ ml.min^{-1}.kg^{-1}$; $p < 0.001$) during a progressively increased speed and gradient walk every 3 minutes until subject chosen failure. The subjects wore a 9.8±0.9 kg vest and the average weight of the subjects was 82.9±11.0 kg for males and 56.1±6.7 kg for females, indicating that the load was 11.8% of body weight for males and 17.5% of body weight for females. Although RPE was not recorded, the physical stress of the walk may have been more of a determining factor of the results, since the subjects chose when to stop.

The results of DeMaio, et al. (2009) using a 9.8 kg vest were consistent with a study from Ricciardi, Deuster, and Talbot (2008) with male and female subjects walking 30 minutes with a 10 kg vest. VO_2 and heart rate increased as a result of wearing the vest, increased speed, and increased gradient (VO_2: 16.8±1.5 vs. 18.8±1.7 $ml.kg.min^{-1}$ and heart rate: 107±14 vs. 118±16 beats per minute at 2.3 – 2.4 mph 5% gradient, and 34.8±3.9 vs. 40.8±5.0 $ml.kg.min^{-1}$ and heart rate: 164±16 vs. 180±13 beats per minute at 3.6 – 3.8 mph with 10% gradient. Collectively, these studies suggest factors such as walking speed, load mass, subject mass, load placement, and incline gradient affect cardiorespiratory physiological and metabolic functions.

Pulmonary function. The restrictive nature of load carrying can have a significant effect on ventilatory threshold. The following studies have investigated the effects of carrying loads on respiratory muscle activity and efficiency. Early studies have relied on the measurement of ventilation via forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and maximum voluntary ventilation (MVV) (Legg, 1988, Majumdar, et al., 1997). Legg and Mahanty (1985) found that placement of the loads seemed to be reported as a cause of ventilatory strain by the subjects. A later study to determine the effects of body armor weighing less than 10 kg by Legg (1988) found a reduction in FVC by 2-3% with similar but not significant differences in FEV_1. Legg drew the conclusion that tightness of fit may be more of a factor of ventilatory stress than mass of the load carried. Majumdar, et al., (1997) ran a study looking at the effects of 9 kg and 11 kg body armor and found small, but significant decreases for FVC, FEV_1, $FVC:FEV_1$, and peak expiratory flow rate (PEFR) for both loads (-6.68 and -8.84, -3.86 and -6.17, +2.86 and +2.86, -2.34 and -5.39% change, respectively), and a significant decrease in MVV for the 11 kg load (-5.20%

change). Minute ventilation (V_E) was significantly higher during a 10 minute treadmill walk at 7.92 km/hr while wearing 11 kg body armor vs. not wearing body armor (9.4 L/min). However, tightness and the effect on the respiratory muscles were not factored in because the subjects were allowed to wear the body armor as desired and did not report exertion or discomfort. Although the results were of greater significant difference than Legg (1988), it was apparent that load mass has a significant effect on pulmonary function.

The following studies have investigated the effect of anatomical restriction of respiratory performance. Harty et al. (1999) simulated the effects of external thoracic restriction on pulmonary function of 10 men wearing a tightly-fitted, inelastic corset designed to support the thoracic vertebrae and restrict rib cage expansion while pedaling at a constant frequency of 60 rpm with a constant workload of ≈65% for 10 minutes. Average total lung capacity, functional residual capacity, residual volume, forced vital capacity, forced expired volume in 1 s, and maximum voluntary ventilation was significantly reduced from unrestricted vs. restricted (7.59±0.80 vs. 4.75±0.84, 3.78±0.66 vs. 2.61±0.47, 1.62±0.47 vs. 1.40±0.41, 6.03±0.68 vs. 3.41±0.71, 4.92±0.70 vs. 2.85±0.64, 185.9±30.5 vs. 122.1±31.3, respectively). Breaths per minute frequency was significantly higher both at rest and during exercise when restricted, while restricted inspired minute ventilation was significantly higher only during exercise and restricted tidal volume was significantly lower during exercise. Further, oxygen pressure and saturation were significantly lower for the restricted condition, and respiratory discomfort scores were significantly higher 3.2±1.3 vs. 35.8±7.1 ($p < .001$) using a 100 mm visual analog scale with the higher the number, the greater the discomfort. It seems that an increase in inspiration and breathing frequency in order to compensate for a shortage in oxygen saturation leads to greater respiratory discomfort accompanied with the restriction of the rib cage mobility.

Coast and Cline (2004), reported similar results when the subjects were performing at maximal effort. The subjects were fitted with a vest with inflatable cushions which increased pressure to the rib cage by inflating cushions in the four different trials at 0 mmHg, 20 mmHg, 40 mmHg, and 60 mmHg. At 60 mmHg, there were consistent significantly decreases in VO_2, time to maximum exercise (when resistance resulted in pedaling with metronome cadence could no longer be achieved), minute ventilation (V_E), tidal volume (V_T), and breathing frequency. At the lesser pressures, there were less significant decreases in pulmonary functions, indicating that not all pulmonary functions are sensitive to the same load amount or a small load increase might not be enough to be detrimental pulmonary function. However, results were consistent with Harty et al. (1999) in terms of significant decreases tidal volume and breathing frequency at submaximal exercise. The small, but insignificant decreases in VO_2 and minutes to maximum exercise under lesser restrictions may have more to do with exercise tolerance (perceived exertion), skeletal muscle fatigue, and pulmonary muscle fatigue (Brown and McConnell 2012). These studies do agree that load carriage increases difficulty in performing pulmonary functions.

Skeletal muscle activity. Most of the research investigating skeletal muscle activity under load bearing conditions have focused on the lower extremity extremities. As load carriage has increased over the past few decades, there has been an increase in musculoskeletal injuries (sprains, strains, and stress fractures) resulting in hospitalizations. In 1994, musculoskeletal injuries were the highest frequented non-battle related injuries accounting for 20%, 17%, 21%, and 14% for the Army, Navy, Marine Corps, and Air Force, respectively (Jones et al., 2000). Although it is unclear if load carriage is the main cause of musculoskeletal injuries, studies have started to investigate how load carriage affects skeletal muscle activity; specifically in gait mechanics.

Ghori and Luckwill (1985) had their subjects carry a load 20% of body weight in either hand. Significant increases in contralateral gluteus medius and ipsilateral gastrocnemius muscle activity indicated that these muscles are the primary balancers of asymmetrical loads. A 50% of body weight load was carried as a back pack. Electromyographic (EMG) data suggested greater activation of the knee extensor muscles even with a significantly shorter swing phase. Harman, et al. (1992) found no significant increases in knee extensor activity, but found increases in gastrocnemius, hamstring and tibialis anterior activity under the same load. It was discussed that the possible increases in lower extremity activity may have to do with the forward lean that is apparent in the trunk during heavy load carriage (30 – 40 kg) walking. Quesada, Mengelkoch, Hale, and Simon (2000) found the greatest effect of load occurred at the knee joint with significant differences in loaded vs. unloaded knee moments pre and post march for 15% of body weight loads and 30% of body weight loads (94.5% vs. 16.3% and 195% vs.74.2%, respectively) as well as, differences in pre and post march stance phase joint angles for the hip, knee, and ankle. The change in moment indicates greater use of knee extensor musculature during the 40 minute march under loaded conditions. The insignificant changes to ankle and hip moment indicate that musculature acting on the joints were not primarily exhausted during marching, but no evidence suggested lesser activity. Blacker, Fallowfield, Bilzon, and Willems (2010) investigated the maximal voluntary contraction and voluntary activation of the rectus femoris following a two hour treadmill walk at 6.5 km/hr with a 25 kg backpack load. Maximal voluntary contraction and voluntary activation decreased from 692 ± 141 to 584 ± 126N and 95 ± 5 and 91 ± 10%, respectively. The results support the increased activation of knee extensors during load carriage walking.

A recent study done by Silder, Delp, and Besier (2013) looked at the muscle activity of the left soleus, medial gastrocnemius, tibialis anterior, hamstring muscle group, and quadriceps muscle group for men and women during four 5 minute walking trials at 1.3 m/s while wearing weighted vests of 0%, 10%, 20%, and 30% of body weight. Peak hip flexion, ankle dorsiflexion, and stance phase knee flexion were found as load increased. Stance phase duration of the total gait cycle significantly increased during the 30% load. All of the muscles significantly increased in activity with increased load for the whole gait cycle with the exception of tibialis anterior, but the quadriceps group did not significantly increase during stance phase. It is conceivable that a loaded weight vest results in less forward trunk lean than a backpack.

Knapik, Reynolds, Harman (2004) indicated that loads placed closer to the center of mass have been found to result in the least amount of energy expenditure. A 1978 study by Grillner, Nilsson, and Thorstensson found a phasic distribution of pressure to the abdominal walls that increases with speed or load amount. The purpose of this phasic distribution is to provide better stability for the lumbar spine. Contraction of the abdominal walls causes an intra-abdominal pressure greater than 200mmHg just prior to foot contact. A drop jump from 0.4 m yielded an increase between 89 and 100 mmHg. It is conceivable that properly distributed load carriage will increase core activation and improve energy expenditure of the erector spinae muscle group.

Most of the research involving core muscle activation investigated muscle activity while lifting and holding loads rather than wearing them. Huang, Andersson, and Thorstensson investigated the activation of core muscles during eccentric and concentric loading movements. In 2001, they observed the muscle activity of the core while the subjects held a static position while holding a 20 kg load and lateral flexing at 0°, 15°, and 30°. During the static positions, it was found that the abdominal muscles developed greater co-activation than other core muscles. Core activation occurred greatest during greater lateral flexion. In 2003, they investigated the effects of different loads on the core lateral flexors. They found a three pattern activation during lateral flexion which started with contralateral activation, then ipsilateral activation, and a final contralateral activation. The greatest magnitude of activation occurred during contralateral activation with the greatest overall % maximum voluntary contraction (MVC) occurring at the external oblique (84%). The transvers abdominis and internal oblique showed a maximum range of 78% and 77%, respectively. These magnitudes and patterns came from lifting the load at a slow, controlled angular velocities averaging 15°/s in order to identify where in the range of motion the muscle activation occurred.

Granata, Orishimo, Sanford (2001) examined co-activation of core muscles with the presence of increasing external forces. They found that core muscle activation did not significantly increase in preparation for sudden abdominal flexion load increases of 2.5% of MVC every trial until 20% MVC. Activation occurred at 55 ms after load impact and peak erector spinae activation occurred at 115 ms. Pre-load weight had the greatest association with a significant increase in preparatory EMG activity for all of the measured trunk muscles. Song, Bok, and Chung (2003) followed a similar experimental procedure with providing an abdominal flexion force of 10, 20, 30, 40, and 50 Nm. Muscle activation was tracked for flexion, extension, lateral flexion, and rotation. Rotational movements resulted in a 34% increase in antagonist co-activation compared with core muscle activation during the other movements. These studies help in identifying predictions of how load carriage might affect reaction to a stimulus and the muscle activation involved in carrying the load based on movement of the torso.

Effects of Load Carriage/Body Armor Combat Related Task Performance

Physical ability tasks. Military and law enforcement combat tasks include marksmanship, hand-to-hand striking, grappling, sprinting while carrying a load, explosive multi-joint movements from seated, supine, or prone positions, using various tools and weapons under fire or life-threatening situations, security, covert operations, and patrol. The duration and intensity of these tasks can vary, but the previous section has eluded to the physiological effects of carrying a load can, in turn, have various effects to performance.

Mello et al. (1988) had their subjects randomly walk 2, 4, 8, and 12 km while carrying a constant load (46.2 kg) at their fastest possible velocity. Further, physiological measurements involving body density lower extremity isometric and isokinetic strength, VO_2 max, and heart rate (HR) max were measured to determine relationships between these factors and load carriage walking performance. Since walking velocity was self-determined, Mello et al. used % max heart rate per kilometer as the determining factor for velocity. As distance increased, % HR and velocity significantly decreased based on the total march time to complete the course most notably from the 2 km distance results to the 12 km distance (165±16 vs. 150±9 bpm and 16.7±2.8 vs. 127.4±12.3 min, respectively). Significant correlations between lower extremity strength measurements of all subjects and march time performance predominantly occurred during the 8 and 12 km distances. Further, subjects who were consistently marching at velocities that resulted in % HR above the group mean %HR also had significant correlations between lower extremity strength measurements and march time performance during the 4 km distance.

Knapik, et al. (1990) included other physiological measurements: upper and lower extremity anaerobic capacity, isometric strength of grip, trunk flexion and extension, and upper torso strength. The subjects completed a 20 km road march carrying a 46 kg load as fast as possible, however results of march times were not reported. Much smaller correlations between the physiological measurements and march time were reported ($p < 0.05$). Abdominal strength had the largest correlation ($r = -0.45$, $p < 0.01$). Knapik, et al. (1993) followed up the study with the effect of 34, 48, and 61 kg loads on road march time wearing the traditional ALICE pack and double pack. As mentioned earlier in this review, heart rate was significantly higher for the 34 kg load. This result is consistent with Mello et al. (1988) that heart rate was higher during the road march that required a lesser amount of work done by subject. As expected, the time to complete the 20 km march was significantly longer as load increased. However, march time was also significantly longer as load increased for the double pack trials compared with the loads carried in the ALICE pack (181±30 vs 171±31, 225±29 vs. 216±34, 276±45 vs. 253±26 minutes, respectively). The subjects also completed a pre and post march 13 event obstacle course. Significant differences were found for all of the events with the exception of the zig-zag run post march as load increased. Further, post road march tests of isometric leg strength revealed no significant differences compared with pre road march tests.

Recent research has investigated load carriage effects on high intense and explosive functional tasks common for military and law enforcement. In addition to physiological effects of wearing a 10 kg weighted vest, DeMaio, et al. (2007) used a BTE Primus RS dynamometer (BTE Technologies Inc, Hanover, MD) and reported that wearing the vest significantly decreased upper extremity climbing ability (46.38±11.1 vs. 51.3± 11.2 reps). Significant decreases were also found during the 300 yard shuttle run ($p < .001$), but not for the 4 cone box drill ($p = 0.28$) or the rope pull and drag dummy drill ($p = 0.42$). Ricciardi, Deuster, and Talbot (2008), reported significant decreases in muscle endurance tests for men and women wearing a 10 kg body armor vest. Pullup repetitions for men decreased by 61%, while hang time for women decreased by 63%. Stair stepping for repetitions in one minute decreased by 16% for the group. However, a significant increase in isometric hand grip strength was found for both dominant and non-dominant hands (37.7±8.2 vs. 38.4±8.2 and 34.9±7.5 vs. 35.6±7.6 lbs, respectively). As expected, the metabolic cost of wearing body armor affected both lower body and upper body muscle endurance. Laing, Treloar, and Billing (2011) reported that the greatest average increase in sprint time occurred during the first 5 meters of a 30 meter sprint (1.0±1.0 sec) while carrying an increased load of 21.6 kg. On average, this increase accounted for 50% of the overall mean increase in sprint time (2.0±0.6 sec). However, the distance covered to reach maximum acceleration was not significantly different indicating that increased load affected acceleration more than linear velocity during short distance sprint performance.

Dempsey, Handcock, and Rehrer (2013) investigated the effect of body armor (7.65 kg) on repeat anaerobic performance after an aerobic performance interval. The study was consistent with significant decreases in sprint acceleration and upper body muscle endurance from chin up repetitions between unloaded and loaded conditions (1.67±0.2 vs. 1.95±0.2 sec. and 8.21±4.8 vs. 5.35±3.9 reps, respectively). Significant increases in time to complete tactical tasks were also found between unloaded and loaded conditions (11±1.8 vs. 12.89±2.2 sec. and 15.85±2.0 vs. 18.16±2.4 sec, respectively). No significant differences occurred in repeat performance efforts for the unloaded condition, but further significant decreases occurred in chin up repetitions and acceleration, as well as, significant increases occurred in time to complete tactical tasks during repeat performance following the aerobic task. The significant increase in metabolic cost during the aerobic task was determined to be a strong factor influencing the repeat performance of the anaerobic tasks. Further, balance ability also significantly decreased with load before and after the aerobic task. This finding suggests that wearing body vests that are specifically designed to evenly distribute weight may actually influence the center of mass to a point where energy expenditure is required to stay balanced. This finding also influences the importance of core muscle strength to perform tasks while carrying excess load.

Cognitive motor skill tasks. The previous literature provides evidence that load can significantly affect performance during aerobic and anaerobic tasks. However, load carriage may be associated with cognitive impairments. Combative tactical tasks require cognitive functions to produce quick reaction time, accuracy and tolerance to prolonged stress. These processes are vital to the successful completion of tasks, missions, and ultimately safety. Pachella (1973) provided a common definition of reaction time as the time between the presentation of a stimulus and the initiation of a response. He further provided a more operational definition of reaction time as the minimum amount of time needed by the subject in order to produce a correct response.

Knapik conducted several studies looking at the effects of different loads on marksmanship accuracy, grenade throwing accuracy, and mood. In 1990, Knapik et al., compared pre and post march marksmanship while carrying a 46 kg load. Marksmanship was performed from a foxhole supported position five minutes after the march. Hits on the target from 25 m away decreased (7.3±2.6 vs. 5.4±2.7, p <.001) and distance from center of the target increased (28.8±13.8 vs. 38.3±14.2 cm, p <.001). The soldiers filled out a profile of mood state questionnaire pre and post march the loaded conditions. Significant differences were found for vigor and fatigue (12.8 ±6.4 vs. 8.0±6.2, p <.001 and 9.1±7.2 vs. 16.6±6.9, p <.001). A higher score indicated a higher feeling. The 1993 study that involved loads of 34, 48, and 61 kg loads with either the ALICE pack or double pack found no significant differences in marksmanship accuracy and grenade throwing accuracy among load mass and load pack, but were significantly different when the march was factored in by itself. The M16 rifles were fired without individual zeroing from a prone unsupported position and the scores were determined based on the distance between each shot in the grouping. Only the vertical distance from center (S_v) was significantly different under load carriage (1.63 vs. 2.34 cm, p = 0.04). There was no significant differences in marksmanship among the three loads. Dummy grenades were thrown from a kneeling position and the largest difference between pre and post march average distances from the center of the target was while wearing the 34 kg load (99±42 vs. 137±63 cm).

Eddy et al. (2015) conducted an auditory go/no go recognition test and a visual target detection test throughout a two hour treadmill walking trial at a constant speed of 4.8 kph and a load carriage of 40 kg. The gradient was a constant 4% for the first hour and varied downhill, uphill, and flat for the second hour. The auditory test consisted of identifying friendly vs. hostile gunfire, while the visual test was identifying enemy targets on a video. Accuracy and reaction time were monitored. Performance in the auditory task was measured using a sensitivity score that represented the proportion of false alarms to hits. Sensitivity scores decreased through time during the first hour, however significant differences were only seen between 25 minutes and 65 minutes due to the significantly higher proportion of false alarms occurring at 45, 65, and 85 minutes during the loaded condition (*t*(9) =3.94, *p*=.003, *t*(9) =4.64, *p*=.001, and *t*(9) =3.29, *p* =.009, respectively. Reaction time was only significantly higher for the loaded condition at 65 minutes (602.83±188.88 vs. 527.98±188.48ms, *p* = .001). Reaction time for the visual stimulus increased linearly and reached significance at 65 minutes when compared with the first block at 15 minutes and continued for the rest of the trial (837.35±61.52 vs. 887.68±70.1 ms). Reaction time was affected more by exercise time during the visual task than the load. These studies provide just a small amount of information with regards to load carriage effect on cognitive processes. Further, to this author's knowledge, the literature has yet to investigate cognitive effects of load during lose quarters combat. The marksmanship tasks for accuracy and visual identification tasks occurred from 25 meters and a televised view that could've given the impression of greater distance. Reaction time and accuracy may be of greater importance with the enemy within arms' reach. The next section will discuss the research pertaining to martial arts and close quarters combat.

Physiological Effects of Close Quarters Combat

Metabolic effects. Close quarters combat involves engagement with an enemy or suspect in close enough proximity where hand-to-hand combat is necessary. It is used to quickly incapacitate, disarm, or restrain the opponent. Army and law enforcement combatives involves a variety of techniques from many different disciplines including: jiu jitsu, krav maga, muay thai, wrestling, and boxing (United States Army Combatives School, 1995). Further, military and law enforcement are trained to use their primary and secondary weapons (ie. rifle buttstock, bayonet, baton, night stick, etc.) in the techniques. The primary function is to position the opponent in such a way where the primary weapon can be used to continue the mission, protecting yourself until backup arrives, or carrying out stealth attacks. The main goal is to provide as much damage as possible with minimal energy expenditure. Techniques and duration vary by situation and research has investigated different disciplines and how duration and intensity affect physiological systems. Since combatives involves high intensity and high contact movements, there is limited research that has been able to investigate physiological effects during combat.

Ghosh et al., (1995) found that on average there were no significant differences in VO_2 between 4 rounds of 2 minutes of sparring each (2x4) and maximal heart rate. Blood lactate was significantly higher for 2x6 sparring than treadmill running (14.5 mmol/L vs. 12.4 mmol/L). Most of the previous research investigated the differences between weight classes. Khanna and Manna (2006) reported that maximal heart rates during exercise and rest were significantly higher for junior boxers (aged 15 – 19) during three 2 minute fight rounds for three different weight classes with the exception of the medium-heavy weight class (74.6±5.4 kg), whose heart rates were higher but not statistically significant compared with graded treadmill exercise with increased velocity and grade (grade I- at 12 km·h-1 speed and 2% inclination; grade II- at 14 km·h-1 speed and 4% inclination; grade III- at 16 km·h-1 speed and 6% inclination, respectively). Butios and Tasika (2007) reported similar results when comparing weight classes during taekwondo performance. The heavyweight division (80 kg) had significantly higher heart rate than the 2 lighter weight classes ($p < 0.05$). There were no inter-weight division and inter-round differences found. An explanation for increased resting heart rate for the fighting round condition may be due to emotions and different muscle groups involved. It was also found that blood lactate levels were significantly higher for the medium-heavyweight group when compared to the lightweight and medium weight groups.

Kravitz, et al. (2003) reported a linear increase in heart rate response to increases in punching tempo during two minute boxing bouts. Of the six punching tempos (60, 72, 84, 96, 108, and 120 b·min), 96, 108, and 120 b·min showed significant increases in relationship with 60, 72, and 84 b·min (120 > 60, 72, 84, 96 b·min; 108 > 60, 72 b·min; 96 > 60 b·min). Ventilation and caloric expenditure differences were also found with faster tempos than slower tempos. However, no significant differences in VO_2 were present among the different tempos. Like the previous studies discussed, upper body striking has shown limited effects on cardiorespiratory. However, this study involved striking as exercise and not for functional performance. Subjects were not required to strike with a specific amount of force.

El-Ashker and Nasr (2012) focused on the effect of an 8 week concurrent boxing specific exercise program on metabolic activity for elite boxers. The three phases of the workouts were equal in workout days, but increased in length and intensity. Phases were split into development of physical abilities (strength, mobility, and endurance), further development of physical abilities specific to boxing, and training for competition with sparring. Cardiorespiratory (peak and resting heart rate, recovery heart rate after 1, 2, and 3 minutes, relative and absolute VO_2 max, and RER significantly differed between pre and post intervention ($p < 0.05$). There was also an increase in blood lactate, creatine kinase, and lactose dehydrogenase ($p < 0.05$). Concurrent strength and endurance training coupled with fight training had a much greater effect on metabolic functions than fight training alone that was discussed previously.

Bouhlel, et al. (2006) investigated the metabolic effects of taekwondo during specific discipline exercises (10 s, 1 min., and 3 min. of front kicks) and simulated competition. Maximum heart rate significantly increased from one round to the next during competition and reached a similar maximum heart rate achieved during the 20 m shuttle test for estimated VO_2 max (197±2 vs. 199±3 beats/min). Blood lactate levels also significantly increased from one round to the next during the competition. Strong positive correlations were found between the specific discipline exercises and competition results for heart rate and blood lactate with the exception of the 1 minute front kick performance trial ($r = 0.85$, $p < 0.05$; $r = 0.39$; $r = 0.95$, $p < 0.01$; and $r = 0.79$, $p < 0.05$; $r = 0.73$, $p < 0.05$; $r = 0.76$, $p < 0.05$; respectively.

Ouergui, et al. (2014) tested the effects of a kickboxing program on aerobic and anaerobic systems. The results could be misleading because the kickboxing program consisted of striking and sparring technical exercises, while the control group consisted of general fitness and sports consistent a high school gym class but very little resistance training and attention to intensity. Significant increases in VO_2 max pre and post intervention, as well as, compared with the control group were found for the kickboxing group (51.9 ± 4.3 58.7 ± 5.2 vs. 51.0 ± 7.8 50.8 ± 6.7 $ml \cdot min^{-1} \cdot kg^{-1}$). Maximal aerobic power, upper body wingate peak power, flexibility, and agility were also significantly higher pre and post intervention for the kickboxing group compared to control group. Taekwondo and kickboxing seem to have greater effects on metabolic systems compared to boxing because of lower body striking and movements of these disciplines. Andreato, et al. (2012) reported similar results of limited metabolic responses to Brazilian jiu-jitsu competition for heart rate (before: 122±25 bpm, after: 165±17 bpm) and lactate (before: 2.5±1.2 mmol/L, after: 11.9±5.8 mmol/L).

Skeletal muscle activity. Contrast to load carriage muscle activity for combatives is primarily focused on the upper extremities. Neto, Magini and, Pacheco (2007) compared the EMG activity of the triceps brachii (TB), biceps brachii (BB) and brachioradialis (BR) muscles during Kung Fu Yau-Man strikes with and without impacts. The TB and BR had significantly higher activation when striking the target compared with no impact (2.12±.10 vs. 4.22±.07 and 1.84±.07 vs. 3.21±.15 *rms*). TB is the primary agonist of the strike and BR is the primary antagonist. The difference in the muscle activity may have been more psychologically motivating because the subjects struck a target rather than just performing the movement.

Striking biomechanics have been used in combative literature to determine muscle activity. Neto. et al. (2008) investigated force kinetics of Kung Fu Yau-Man palm strikes of experienced practitioners compared with novice participants with athletic backgrounds. Mean muscle and impact force were significantly higher in the experienced group compared with the novice group (132±30.4 and 355±96.5 N vs. 89±19 N and 233±42 N). Mean muscle power and impact power was also significantly higher (479±196 and 1756±809 W vs. 245±59 and 722.2±261 W). Hand speed for the experienced group was significantly higher (7.06±1.55 vs. 5.57±1.01 m/s), indicating that the upper arm muscles involved in the strike fired much more efficiently to produce the force and power results (72±9% vs.

55±9%). Further correlations found between muscle power and impact power were greater than the novice participants fortifying strike efficiency ($\rho = .99$, $p < .001$ vs. $\rho = .46$, $p = .35$).

Mack, et al. (2010) observed the punch force and hand velocity of amateur boxers. In contrast to the Kung Fu Yau-Man palm strikes there was greater hand velocity and punch force for both the hook and jab, with the hook significantly greater than the jab. In order to determine how much of punch force was dictated by hand velocity, correlations were run for punch force with hand velocity and the sum of lower body forces corresponding with each strike. Significant correlations were found for hook and jab punch force with both hand velocity and lower body forces, but stronger with hand velocity ($R^2 = 0.380$, $p < 0.001$ and $R^2 = 0.391$, $p < 0.001$ vs. $R^2 = 0.103$, $p = 0.043$ and $R^2 = 0.099$, $p = 0.048$). These results indicate that muscle activity is greater in the upper extremities for strikes from boxing and Kung Fu, but lower body muscle activity is greater for boxing. This increased total muscle activity may be a factor for the increase in hand velocity and resulting punch force for boxers.

Muscle activity in upper extremity striking has been shown to be dependent on discipline technique. Muscle activity differences in lower extremity strikes was studied by Sidthilaw (1996) for Muay Thai roundhouse kicks. At a kicking speed of 120°/sec, knee extension yielded greater peak isokinetic force than hip flexion (193.8±33.7 vs. 159.3±38.2 Nm). Kicks were performed at three different levels with significantly higher mean peak forces at the low (knee height) and middle (hip height) levels compared with the high (shoulder height) level (6702±3514, 7420±3477, and 5618±3253 N, $p < 0.05$). Linear and angular velocities at the knee showed no significance, but peak force was significantly correlated with final ankle velocity (*r* = .86). These results indicate that proximal to distal muscle activation occurs in such a way to produce maximal force at the most distal end.

Machado, Osorio, Silva, and Magini (2010). A comparison of taekwondo and kickboxing techniques yielded no significant differences in muscle activity or impulse with the exception of the vastus lateralis muscle. Kickboxing vastus lateralis muscle yielded greater activity (8.4996±0.97 vs. 6.969±0.66 mV^2), however peak torque of the knee extensors yielded no significant differences. The results were unexpected because of the 5 year training advantage for the taekwondo practitioners. These slim differences illicit the idea that upper extremity striking requires more training for efficiency, but lower extremity striking may require less training for optimal performance. Therefore, it can be concluded from the research that lower body extremity usage may affect metabolic function, but muscle activity efficiency for performance may be more of an upper extremity characteristic.

Cognitive Effects of Close Quarters Combat

Reaction time. The importance of the ability to strike forcefully and efficiently may be exceeded by the importance of responding to the actions of your opponent and where to strike. Darby, et al. (2014) tested the reaction time of boxers during a tournament. The boxers who advanced to the semifinal round of the tournament averaged significantly faster times in processing speed, attention task speed, learning task speed, and working memory speed prior to their semifinal bouts compared to pre-tournament baseline averages for all of the fighters (294±31 vs. 321±42, 428±42 vs. 457±58, 790±93 vs. 860±138, 550±74 vs. 628±115 ms, respectively). In comparison of their own baseline pre-competition results, speed composite (z-score) was significantly higher than the pre-competition baseline for the rest of the fighters: F(1,94) = 4.14, $p < 0.05$, effect size 0.54. These results indicate that reaction time may be a predictor of success for combatives. Although this study seemed to find a relationship between faster reaction time tests and performance success, it follows the issue of previous research that uses non-combative tests.

Bianco et al. (2011) compared the effects of simple and choice reaction times on gender and during a baseline neurophysiology test. No significant differences were found between genders, however rate of mistakes were significantly less for both males and females from the detection 1 task to the detection 2 task (0.7±1.6 vs. 2.0±3.1% and 0.5±1.1 vs. 2.2±3.0%, $p < 0.05$, respectively). Coşkun, Koçak, & Saritaş (2014) compared auditory, visual simple and visual choice reaction times among different age groups and status (national and international) of karate athletes. The participants responded to the stimuli while pushing a button. Although significant differences were found between younger age groups and older age groups, as well as, between national and international status for the auditory stimulus, these tests did not show how reaction time affected performance in combat situations or movements.

The ability to rapidly change direction or move without losing balance and using a combination of muscular strength and power is the definition of agility (Turner, 2011). However, agility performance starts with the ability of the central nervous system to produce action potentials at the neuromuscular junction to produce force for these movements. “Agility skills that are characterized by 3 information processing stages, such as stimulus perception, response selection, and movement execution, represent a crucial part of performance in many sports” (Zemkova, Vilman, Kovacikova , and Hamar, 2013). Martial artists spend many hours studying video of their opponents and sparring to practice reading their opponents movements, identifying and avoiding strengths, and exploiting weaknesses. Military and law enforcement do not have that luxury, so the ability to cognitively identify and react to an attack is practiced continuously.

The previous literature investigated reaction time in non-competitive settings that involved non-competitive movements. Zemkova, Vilman, Kovacikova, and Hamar (2013) investigated reaction time difference between non-competitive settings with movement and simulated competitive settings with movement. Average reaction time significantly decreased from the non-competitive condition to the competitive condition (805.8±101.1 vs. 690.6±83.8 ms). Further, the winners of the first competitive trial participated in a second trial and further significantly decreased average reaction time from the first competitive trial (637.0±53.0 ms). These results were consistent with the Darby, et al. (2014) study which showed the more successful subjects progressively performed reaction time tasks faster. Using the same experimental setting Zemková and Hamar (2014) compared the ability of different sports participants to move their foot in reaction to a visual stimulus. Fencing, taekwondo, and karate yielded significantly faster agility times (336.6 ± 26.1, 338.7 ± 23.9, 339.4 ± 25.6 ms, respectively) than other combative sports: aikido, judo, and wrestling (409.1 ± 38.0, 454.6 ± 44.9, 497.6 ± 44.4 ms, respectively). It was determined that in the field of combative sports, disciplines that are predominantly striking rely more on reaction time to a visual stimulus than grappling disciplines where posture and body positions are more important based on the opponent’s movements.

Mori, Ohtani, and Imanaka (2002) presented their subjects with choice and simple reaction time tasks which consisted of video clips of different karate attack statures or the presence of dots. The subjects had to identify if the attack was intended for the upper chest and head region or the abdomen region. At random, the dot clip was presented in the upper section of the screen or lower section of the screen. It was found that choice reaction time for the video was significantly slower than the dot choice reaction time test for both groups (F(1,22) = 1297.57 for the athlete and F(1,22) = 2118.48 for the novice). Between groups, the athlete group was significantly faster. No significant differences were present for the simple reaction times for either within group or between group comparisons.

Chen, et al. (2015) most recently conducted a study involving reaction time to a dual task involving taekwondo experts and novices performing four different kicks with progressive complexity on a combat dummy with a visual stimulus. The expert group averaged 14.0% faster premotor reaction time and successive 16.5 -18.2% faster reaction times for the next three movements. This could imply that when the visual stimulus occurred, the experts had greater ability to produce the force necessary to perform the movement greater than the novice group. However, the time to complete the movement had no significant differences and the completion of the secondary reaction to the visual stimulus was significantly faster for the expert group (0.252±0.030 vs. 0.351±0.063 ms). The previous research has indicated that success in combatives is heavily affected by reaction to stimuli as much as production of force and power. However, it seems that the literature is lacking in reaction time studies during actual combat scenarios and movements and the production of combative movements in response. Further, military and law enforcement have to be able to be productive in reaction time and movement with the burden of increased load carriage.

Conclusion

After a comprehensive review of the literature, assumptions can be made of increased metabolic demand of carrying loads during exercise, specifically combat related tasks. The metabolic demand can be determined by load mass, body mass, speed of the task, terrain and obstacles, and aerobic capacity. Increased metabolic demand may have varied detrimental effects on cognitive and physical performance. However, a significant combat task remains to be studied for potential effects from load carriage. Close quarters combat tasks have been shown to be primarily anaerobic due to the short, high-intense nature of the movements. However, duration and magnitude of the movements require cardiorespiratory responses. Cognitive results of combatives have an effect on successful performance and seem to improve with training, experience, and competition. However, the effects of load carriage on reaction time during close-quarters combat need to be studied in order to discover potential detriments to combat skills needed to complete missions and keep tactical personal safe. The goal of this study is to provide information of potential detriments to reaction time under load, and if abdominal muscle activation may be a factor in the results.

CHAPTER 3

METHODS

Prior studies have not investigated the effects of load carriage on close-quarters combative movements during a simulated scenario to respond to an assailant; an essential ability for military and law enforcement to carry out missions and survive sudden hostile attacks. The purpose of this study was to determine if body armor affects an individual's ability to react or counter a simulated attack by performing correct combative movements in response to the stimulus.

Experimental Approach

As in the study by Chen, et al. (2015), the movements of participants were analyzed on their ability to react in a simulated close-quarters combat situation by performing combative movements based on a visual stimulus. The participants performed the combative movement in clothing only (unloaded) and wearing a 10 kg Golds Gym® adjustable weighted vest (Model# HHWV-GG020C) that covered the thoracic, upper abdominal area and the upper and middle back (loaded). The purpose of the weighted vest was to simulate body armor (Dempsey, Handcock, Rehrer, 2013).

Participants

Ten healthy, physically active volunteers (9 male and 1 female) were recruited from the SUNY Cortland student body (age: 21.5±2.3 years, height: 1.81±0.1 m, weight: 92.2±16.7 kg). The number of participants was consistent with Chen, et al. (2015). The sample population was determined using G-Power 3.1.9.2 (Franz Faul, Universität Kiel, Germany © 1992 – 2014). Effect size (f) of 0.5 and power (1 – ß err prob) of 0.8 yielded a sample size of 10. Bianco, et al. (2011) found no differences in baseline reaction time of male and female boxers, so no differences between genders were assumed. All of the participants were provided written consent statements (Appendix B) and physically active readiness questionnaires (PAR-Q). The consent forms provided the participants information regarding objectives of the study, potential health risks, requirements, and procedures. In the PAR-Q (Appendix C), the participants reported no current musculoskeletal injuries, visual impairments, or dermatological allergies to silver or adhesive that would negatively affect their ability to complete testing.

All of the participants reported having at least six months of experience in a discipline that involved upper body striking (5.6±4.8 years). Four of the participants had backgrounds in boxing, two had backgrounds in Muay Thai, two had backgrounds in military combatives, one had a background in Kempo, and one had a background in Taekwondo. Two of the subjects reported military experience, while one subject reported training with a weighted vest but not for combatives. The subjects were told to adhere to their current training, nutrition, supplementation, and sleep schedule, and agreed to refrain from any excessive stimulant (caffeine) or depressant (alcohol) ingestion at least 24 hours prior to testing.

Materials and Equipment

The visual stimulus consisted of 4 red 9V 5mm LED lights positioned in a rectangular pattern on a board separated in a 9” x 12” configuration. The board was mounted on the wall approximately 5 ft. in front of the subject and 6 ft. above the floor. Above each light was a sign indicating which movement they are to perform when the light was illuminated. The lights were wired to a breaker box with 8-12 mm 9V push button switches that the researcher used to simultaneously control illumination of the stimulus and activation of the Therapeutics Unlimited Model 544 Multichannel Electromyographic (EMG) System (Iowa City, IA) with four amplifier/processor modules. Metal pieces were used to bridge the four push button switches for the individual lights with the switches that activated the capture window of the EMG, so each light was isolated and the EMG activated for each light (Figure 1). Signs were placed over the lights indicating which movement to perform when the light is illuminated (Figure 1).

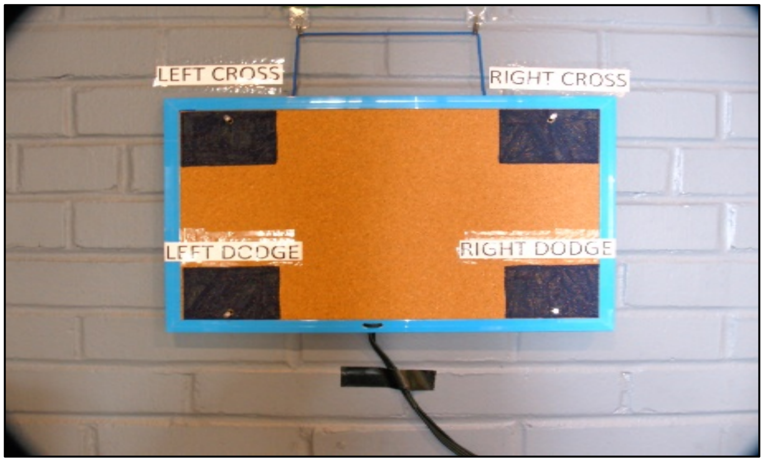

Figure 1 – Four LED visual display with movement signs. The subjects performed the movement labeled when the coinciding light illuminated

Four bipolar silver-silver chloride surface electrodes were placed on the subject's abdomen and reinforced with medical tape and an adjustable waist belt: for the right and left rectus abdominis, electrodes were placed slightly above and on either side of the umbilicus; for the right and left external oblique electrodes were placed directly superior to the anterior superior iliac spine and in line with the umbilicus at an orientation of 45° to vertical (Granata, Orishimo, & Sanford, 2001). The ground electrode was placed on the participants' right patella.

During each trial, surface EMG (sEMG) signals were transmitted along the electrode cables to the EMG unit and amplified by a factor of 20,000. The analog signals were treated with a 20 Hz low cut, high pass filter. The root mean square (RMS) of the filtered signal was computed using an 11.75 ms moving time window as per the following equation:

$$f_{rms}(t) = \sqrt{\frac{1}{T_2 - T_1}\int_{T_1}^{T_2}[f(t)]^2 dt}$$

where, $f(t)$ = myoelectric signal at time, t

$f_{rms}(t)$ = RMS of the myoelectric signal at time, t

$T_2 - T_1$ = 11.75 ms, the size of the moving time window

$$T_2 = t + \frac{(T_2 - T_1)}{2} = t + \frac{2.5\,ms}{2} = t + 5.875 \text{ ms}$$

$$T_1 = t - \frac{(T_2 - T_1)}{2} = t - \frac{2.5\,ms}{2} = t - 5.875 \text{ ms}$$

The Peak Motus® motion analysis system (Peak Performance Technologies, Inc., Centennial, CO) was used to sample each analog signal at a rate of 1020 Hz and converted and stored the signal digitally. The pre-trigger and post-trigger times were set at 0.1 and 1.0 sec., respectively. The trigger was recorded by the Peak System and the reaction time was determined as the time from the onset of the trigger signal to when the RMS EMG exceeded the 0.5 V for one of the EMG signals. Each electrode was color coded with the digital signal that was displayed on the digital screen. The first digital display that reached the 0.5 V RMS was considered the end of the reaction time period. Magnitude of muscle activation for all four muscles during each trial was determined by the averages of the RMS values over one second.

The subjects were given 4 oz. open-fingered bag gloves to wear and strike the standing bag. The purpose of the standing bag and target is to provide a threshold for the participant to perform a successful trial requiring a strike (cross) and provided motivation for maximum effort (Zemkova, Vilman, Kovacikova, & Hamar, 2013). The bag was adjusted so the top of the bag measured 65” high, and the target on the bag the subjects’ struck was the “FIT” lettering presented on the standing striking bag which was placed between the subject and the LED display. Weights were placed in the plastic stand to prevent movement of the bag after striking. Distance from the punching bag was determined by measuring the subject’s reach to pass the front of the bag by 1”. The reach distance adjustment allowed the participant to strike the bag with maximum effort, and prevent full elbow extension affect results. Hanging from the crossbar were two bungee cords placed on both sides of the subject. The bungee cord set up provided a threshold for a successful trial requiring lateral flexion (dodging) and was adjusted using quick release clamps positioned on the crossbar.

One high definition digital cameras (JVC® 36Mbps Progressive, S/N 077501106 made in Malaysia) was set up at 30 degree angles from the right and left of the back support racks with the lenses placed 30 cm from the racks. The camera was positioned so the subject’s head and shoulder, visual lighting display, striking bag, and bungee cords were seen and continuously recorded all of the trials during the session. The purpose of the camera was to provide footage of each trial to assure each movement was correctly completed.

Procedure

Each participant was tested three separate times during 30-45 minute testing sessions. All three sessions took place in SUNY Cortland’s biomechanics lab. The first session consisted of completing a PAR-Q for physical activity readiness, brief medical and recreational history specific to the study, and anthropometric testing: age, height, and body mass. Following all measurements, the subjects completed a familiarization block of 20 trials responding to the visual stimulus with the correct movements without the use of the EMG. A score of less than 90% correct movement choice based on the illuminated light, reaction time greater than one second, or failure to reach the threshold for the movement resulted in a five minute rest and a repeat of 20 more trials. An additional block of 20 trials was also performed by the participants while wearing the body vest with the use of the visual stimulus and random foreperiods (time prior to the initiation of the stimulus) between trials ranging from 10-20 seconds to acclimate them to performing combative movements under a loaded condition.

The second testing session occurred a minimum of 48 hours after the first session. The participants entered the testing facility with shaved and cleaned abdomens for the electrode placement, and randomly placed into the weighted or unweighted conditions. The electrodes were attached with double stick mounting tape and a conducting gel was used to improve contact conductivity. After placement of the electrodes on the abdomen, the placement of the electrodes were reinforced with medical tape and a neoprene belt wrapped around the subject’s abdomen to ensure restriction of electrode movement. The subjects stood in standard forward guard position with their hands in fighting position. The researcher followed a script of random illumination of an LED and triggered the light and EMG. The subject responded with the following movements: lower left illumination will be a dodge (lateral flexion) to the left, upper left will be a left cross strike, lower right will be a dodge to the right, and upper right will be a right cross strike as fast as they can (Figure 2).

The foreperiod time between repetitions varied with a minimum time of 10 sec. to a maximum time of 20 sec. to control for anticipation. The passing criteria and number of blocks allowed to complete the passing criteria was the same as the familiarity session: a score of less than 90% correct movement choice based on the illuminated light, reaction time greater than one second, or failure to reach the threshold. The third session took place at least 24 hours after the conclusion of the second session. The participants followed the same procedure as the second session. However, participants who wore the weighted vest during the second session performed the 20 trials without the weighted vest. The participants who did not wear the weighted vest during the second session performed the 20 trials with the weighted vest.

Figure 2 – Left dodge in response to lower left light.

Statistical Analysis

For the primary analysis, the independent variable was the unweighted vs. weighted condition, and the dependent variables were reaction time and muscle activation. Differences in the dependent variables between the conditions, as well as, interactions between the dependent variables were analyzed. The data for each trial was recorded by the

Peak Motus System and saved to a disk. Following all the testing sessions, the data was transferred from the disk to a USB drive where it can be uploaded for analysis. Statistical analyses were run using SPSS version 23 (IBM Corp. Released 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp).

Descriptive statistics were run for age, height, body mass, years of experience, average reaction time for completing the four movements in both conditions, and average muscle activity for the four abdominal muscles in both conditions when the 0.5 V threshold was reached. A two-tailed paired samples t-test was run to determine differences between the average reaction time and average RMS sEMG for each core muscle during each movement for the unweighted and weighted conditions. A one-way ANOVA with repeated measures was run to determine significant differences in average reaction time and average total muscle activity between the unweighted and weighted conditions for the group. Alpha was set at 0.05.

CHAPTER 4

RESULTS

The purpose of this study was to investigate the effects of wearing a weighted vest on choice reaction time and sEMG core muscle activity initiating movement in response to a simulated close-quarters combat scenario. The average reaction time to initiate a response to a visual stimulus and average total RMS sEMG of the core muscles for each movement was compared between an unweighted condition and a weighted condition. The subjects completed either a right cross, left cross, right dodge, or left dodge based on the stimulus presented. sEMG of the left oblique, left rectus abdominus, right rectus abdominus, and right oblique were recorded to identify when response to the stimulus was initiated and the magnitude of sEMG at the initiation of the movement.

Results

The values for means and standard deviations of average reaction time for the four core muscles among all the participants are shown in Table 1. Significant differences between the unweighted and weighted condition were found in mean reaction times for the left dodge ($p = 0.047$), right cross ($p = 0.014$), and the right dodge ($p = 0.002$). The difference between the unweighted and weighted mean reaction time for the left cross was not significant ($p = 0.059$). However, overall mean reaction time for the entire group was significantly different between the unweighted and weighted conditions ($p = 0.001$).

Table 1. *Means and Standard Deviations of Average Reaction Time in Milliseconds for the Four Movements Performed by Ten Participants.*

	Reaction Time (ms)		
	w/o vest	*w/ vest*	*difference*
Left Cross	366.7 (107.2)	407.8 (99.2)	41.1
Left Dodge	372.3 (83.1)	425.9 (136.9)	53.6*
Right Cross	359.2 (105.2)	411.0 (120.2)	51.8*
Right Dodge	345.7 (108.9)	401.2 (114.3)	55.5*
Group Average	361.0 (11.5)	411.5 (10.4)	50.5*

*$p < .05$

No significant differences in mean RMS sEMG activity were found among the core muscles (Table 2). The mean RMS sEMG for the left rectus abdominus showed the greatest difference between the unweighted and weighted condition during the left cross movement ($p = 0.088$). Even though no significant differences were found, the greatest differences in RMS sEMG muscle activity (V) between conditions occurred in the left rectus abdominus, right rectus abdominus, and right oblique while performing the left cross (0.17 ± 0.11 vs. 0.26 ± 0.18, 0.21 ± 0.14 vs. 0.28 ± 0.15, and 0.41 ± 0.16 vs. 0.35 ± 0.16, respectively). The mean RMS sEMG activity for the left and right obliques decreased (0.35 ± 0.14 vs. 0.32 ± 0.14 and 0.34 ± 0.14 vs. 0.31 ± 0.14, respectively) with the weighted vest, while the mean RMS sEMG activity for the left and right rectus abdominus increased (0.22 ± 0.07 vs. 0.25 ± 0.07 vs. 0.21 ± 0.04 vs. 0.25 ± 0.07, respectively). Further, there were no significant differences in mean overall core muscle activity between the unweighted and weighted conditions (1.10 ± 0.06 V vs. 1.13±0.05 V, $p = 0.482$).

Table 2. *Means (x̄) and Standard Deviations (SD) of RMS sEMG in Volts for the Four Movements Performed by Ten Participants.*

	left oblique RMS (V)		left rect. abd. RMS (V)		right rect. abd. RMS (V)		right oblique RMS (V)		overall core RMS (V)	
	w/o	*w/*	*w/o*	*w/*	*w/o*	*w/*	*w/o*	*w/*	*w/o*	*w/*
Left Cross	0.27	0.26	0.17	0.26	0.21	0.28	0.41	0.35	1.06	1.15
SD	(0.15)	(0.13)	(0.11)	(0.18)	(0.14)	(0.15)	(0.16)	(0.16)	(0.14)	(0.16)
Left Dodge	0.51	0.46	0.27	0.28	0.15	0.16	0.20	0.17	1.13	1.07
SD	(0.05)	(0.14)	(0.15)	(0.19)	(0.08)	(0.08)	(0.08)	(0.08)	(0.09)	(0.12)
Right Cross	0.42	0.41	0.28	0.32	0.23	0.23	0.25	0.22	1.18	1.18
SD	(0.13)	(0.14)	(0.11)	(0.15)	(0.14)	(0.14)	(0.14)	(0.10)	(0.13)	(0.14)
Right Dodge	0.19	0.15	0.15	0.15	0.23	0.31	0.50	0.49	1.07	1.10
SD	(0.08)	(0.09)	(0.08)	(0.19)	(0.15)	(0.19)	(0.09)	(0.11)	(0.10)	(0.14)
x̄ RMS sEMG	0.35	0.32	0.22	0.25	0.21	0.25	0.34	0.31	1.10	1.13
SD	(0.14)	(0.14)	(0.07)	(0.07)	(0.04)	(0.07)	(0.14)	(0.14)	(0.06)	(0.05)

The mean reaction time for all four movements and the mean group average are illustrated in Figure 3. Interestingly, the significant differences in mean reaction time between the unweighted and weighted conditions were similar for the left dodge, right cross, right dodge, and group average (53.6, 51.8, 55.5, and 50.5 ms, respectively).

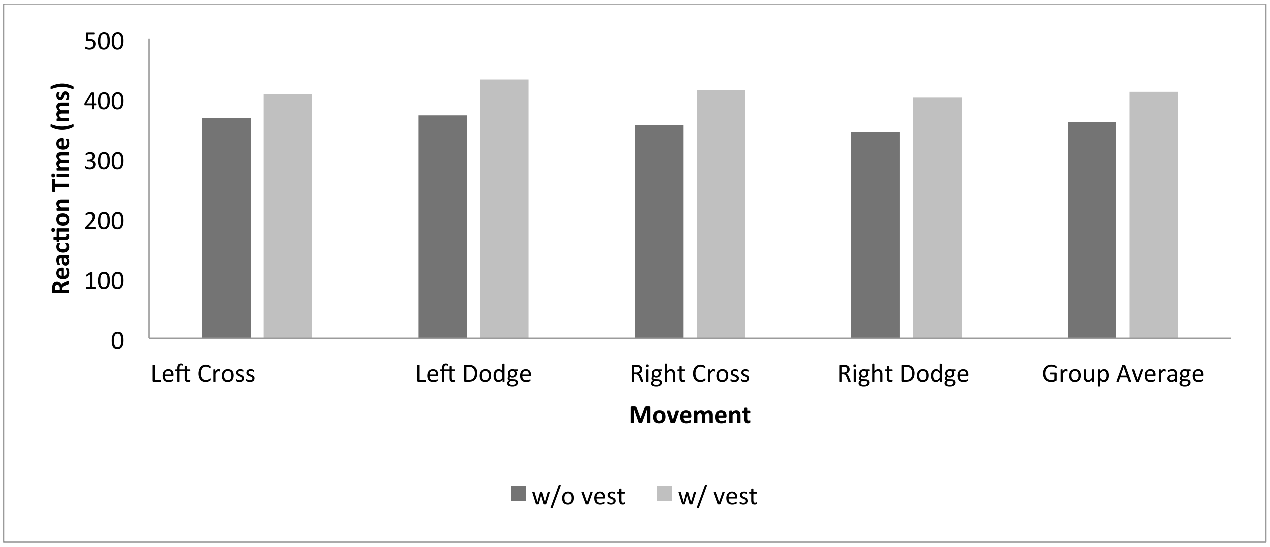

Figure 3 – Mean reaction times of the ten participants performing the left cross, left dodge, right cross, and right dodge.

The standard deviations of the reaction times (ms) of the ten participants for the left cross, left dodge, right cross, and right dodge are illustrated in Figure 4. The standard deviations for the left dodge, right cross, and right dodge movements were greater for the weighted condition than the unweighted condition (83.1 vs. 136.9, 105.2 vs. 120.2, and 108.9 vs. 114.3) with the exception of the left cross (107.2 vs. 99.2). The largest difference occurred in the left dodge movement (83.0 vs. 130.7). Mean reaction time was greatest among the subjects for the left dodge in the unweighted condition with the smallest standard deviation, but also had the largest reaction time and largest standard deviation in the weighted condition (372.3 ± 83.1 vs. 425.9 ± 136.9 ms).

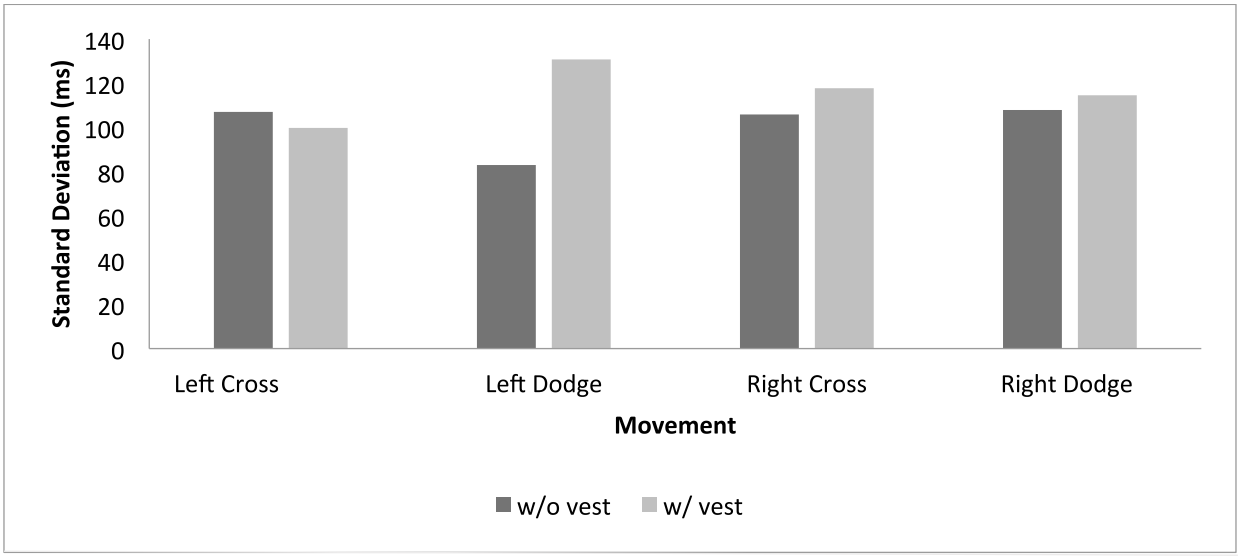

Figure 4 – Standard deviations for reaction times of the ten participants performing the left cross, left dodge, right cross, and right dodge.

The left dodge and right dodge were primarily activated by the left obliques and right obliques in both conditions (0.51 ± 0.05, 0.46 ± 0.14 and 0.50 ± 0.09, 0.49 ± 0.11, respectively). However, overall sEMG core muscle activation was not significantly different among all four movements in either condition. The largest standard deviation for all the movements occurred in the left rectus abdominus while wearing the vest with the exception of the right rectus abdominus while wearing the vest for the right dodge (0.18, 0.19, 0.15, 0.19, and 0.19, respectively). The largest differences in standard deviation between the unweighted and weighted conditions also occurred in the left rectus abdominus for all of the movements, specifically the right dodge (0.11 vs. 0.18, 0.15 vs. 0.19, 0.11 vs. 0.15, and 0.08 vs. 0.19, respectively).

CHAPTER 5

DISCUSSION, SUMMARY, CONCLUSION, IMPLICATIONS, AND RECOMMENDATIONS

Discussion

The results of this study support the first hypothesis: that choice reaction time significantly increases while wearing the weighted vest. However, the second hypothesis: that sEMG core muscle activity to initiate movement increases by wearing the weighted vest was not supported.

As previously stated, prior research has found similar decrements in cardiopulmonary, muscular endurance, and muscular power performance while carrying a load. Further, prior research has found that load lifting/placement and mass also affect muscle activity and performance. In this study, load placement was a constant 10 kg and placed over the chest cavity and upper back. Huang, Andersson, and Thorstensson, (2003) found no significant differences in abdominal muscle activation at the initiation of unilateral trunk flexion movement of 0kg, 2kg, and 20kg loads. The participants were lifting the loads, not wearing them. However, muscle activation increased on the contralateral as the movement continued. Since initiating the movement in combatives is important in reacting to an opponent's move, the second purpose of this study was to determine if muscle activity to initiate movement would increase under a loaded condition. The lack of significant results were consistent with Huang, Andersson, and Thorstensson (2003). Table 2 did show a trend that muscle activity for the left and right obliques decreased with the weighted vest, while the mean RMS sEMG activity for the left and right rectus abdominus increased. This could indicate that the participants compensated for wearing the weighted vest by activating the rectus abdominus musculature more than the obliques in order to perform the combative movement; which also may have contributed to increased reaction time.

Table 1 showed similar differences between the unweighted and weighted conditions and small standard deviations for the group average of the unweighted and weighted conditions. This indicates that the mean reaction times for both conditions may be true means. Since there were no significant increases in muscle activity from the unweighted to the weighted condition to go along with the significant increases in reaction time, the difference in reaction time may be cognitive (Turner, 2011). Mean reaction time was greatest among the subjects for the left dodge in the unweighted condition with the smallest standard deviation, but also had the largest reaction time and largest standard deviation in the weighted condition (372.3 ± 83.1 vs. 425.9 ± 136.9 ms). Reaction time is a component of neuromuscular function based on the ability to respond with a movement to a sensory stimulus (Turner, 2011). This data indicates that the left dodge may have been the more difficult or more unnatural movement to perform. This could have been attributed to unfamiliarity with wearing the vest and compensating for the vest with a slight delay of movement by less experienced subjects. The standard deviations for the group means were low, indicating that regardless of the movement, mean reaction time was similar throughout the study and varied on a similar scale with the presence of the weighted vest.

In this study, participants produced single movements in response to a simple light stimulus in a controlled environment. Mori, Ohtani, and Imanaka (2002) conducted a study and found that reaction time was significantly less than responding to a video stimulus.

Chen, et al. (2015) found that reaction time to a simple light increased as complexity of the movement increased. Zemkova, Vilman, Kovacikova, and Hamar (2013) found an increase in reaction time during a non-competitive situation compared with a competitive situation. Although the study environment was made in an attempt to accommodate favorable reaction time based on these findings, average reaction time increased from the unweighted to the weighted condition.

Zemkova, Vilman, Kovacikova, and Hamar (2013) determined that a competitive setting may affect performance due to focusing on defeating the opponent. The weighted vest may have provided a cognitive distraction from the task as much as a possible change in physically performing the movement from the restriction of wearing a weighted vest. Figure 6 shows the standard deviations for each mean reaction time of the individual movement. During this study, the lights representing each movement were illuminated in random order with random foreperiods of 10 – 20 seconds between trials. This combination of random illumination and foreperiods may have restricted anticipation and guessing by the participant. The lights may have illuminated more often at a time and movement not expected by the subject.

The participants were positioned so striking the bag would not result in full extension of the elbows and the participants could naturally strike the bag the way they were accustomed. Some of the participants noticed discomfort in the upper extremities while performing the weighted trials, specifically muscle soreness in the upper trapezius, deltoids, and triceps. This discomfort may have caused distraction for responding to the stimulus, and slight differences in RMS sEMG muscle activation location during the movements. Although effects on upper extremity were not measured, these observations are consistent with Neto, Magini and, Pacheco (2007). Increasing the load may have had a greater effect on the upper extremity musculature than the abdominal musculature.

Since techniques may vary among disciplines to a degree, the wearing of the weighted vest may have altered performance of the technique for some of the participants based on their discipline and may explain the reason for the greater standard deviations in the weighted condition. The sEMG muscle activity for the left and right cross resulted in more even distribution for all the core muscles possibly due to different striking techniques of the subjects' disciplines. The original forward guard position may also have been altered by the participants showing favor to the left side. Further, the stress of wearing the vest may not affect the amount of muscle activation required for movement initiation, but may affect activation for the whole movement. Participants did not indicate that they were physically fatigued even though they felt muscle soreness.

Since Chen, et al. (2015) found no significant difference in expert vs. novice reaction time when performing simple movements, it was assumed that reaction time for simple movements would be similar among all of the subjects regardless of experience. However, another possible explanation for the high standard deviations for the reaction times is because of the variance in experience among the participants (5.6±4.8 years, 0.5 min and 16 max). Sports specific training and experience has been shown to decrease reaction time. Song and An (2004) found a significant decrease in reaction time between mentally disabled youths who trained for seven months in the taekwondo discipline and mentally disabled youths who completed agility training. According to Appendix A-1, participant 1 had the smallest standard deviations while wearing the vest and also had shorter reaction times unweighted. This participant listed 11 years of martial arts experience. Some of the participants were able to perform the movements faster while wearing the vest. These participants either had prior military experience or years of experience in martial arts that was greater than the mean. However, these performance differences rarely occurred throughout the study and may be more of a result of the random illumination and foreperiods between trials.

Summary

The purpose of this study was to investigate the effects of wearing a weighted vest on choice reaction time and sEMG core muscle activity initiating movement in response to a simulated close-quarters combat scenario. The average reaction time to initiate a response to a visual stimulus and average total RMS sEMG of the core muscles for each movement was compared between an unweighted condition and a weighted condition. It was hypothesized that that wearing the weighted vest would significantly increase choice reaction time and significantly increase the core muscle activity in order to initiate movement. The participants were healthy, active individuals from the SUNY Cortland student body with at least six months of martial arts/boxing experience. Reaction time and sEMG data were collected for four striking conditions. These systems recorded the frequency and amplitude of the myoelectric activity and derived the reaction time and RMS sEMG from this data when the peaks reached a minimum threshold of 0.5 V. sEMG activity of the left and right abdominals and the left and right rectus abdominus were recorded when the threshold of 0.5 V was reached indicating muscle activity required to initiate movement. 20 trials were completed for both the unweighted and weighted conditions during separate sessions. Means and standard deviations were computed for the reaction times and RMS sEMG data were for each of the four movements. A two-tailed paired samples t-test was run to determine differences between the average reaction time and average RMS sEMG for each core muscle during each movement for the unweighted and weighted conditions. A one-way ANOVA with repeated measures was run to determine significant differences in average reaction time and average total muscle activity between the unweighted and weighted conditions for the group.

Conclusion

It was concluded from this study that wearing a weighted vest resulted in significantly higher mean reaction time to a visual stimulus simulating a close-quarters combat movement. No significant differences were found in mean RMS sEMG muscle activity to initiate movement, so no interaction was determined between increased reaction time and increased core muscle activation.

Implications

It is important to understand how personal protective equipment affects all aspects of tactical performance. It is also important to understand that tactical performance depends on the ability to react to potentially life threatening situations whether the threat comes from long distances or within arm’s reach. Any hindrance of physical ability or cognitive distraction could have consequences to the mission and safety of those involved. Prior research discussed in this study has identified detriments to physical ability in other tactical performances while wearing protective gear. The results of this study indicate that wearing a weighted vest comparable to protective body armor can decrease reaction time to simulated combat scenarios and contribute to the importance of situation specific training for subjects who may encounter real world scenarios where these skills will have to be executed in protective gear.

Combatives involves much more than striking and dodging. Combatives instructors, specifically military and law enforcement, can use this information as a means to further protect the armed forces by training them in the protective gear that they will be wearing out in the field. Further, understanding how a weighted vest affects physical and cognitive function will help combatives instructors develop agility for armed forces while grappling, sprawling, secondary weapons training, and other forms of combatives. These results can also help amateur and professional fighters in different disciplines train to increase their overall agility while performing combative moves in response to their opponents.

Recommendations

Future research should be conducted to more accurately determine muscle activation using intramuscular EMG in the abdominal muscles. This method of testing would further eliminate muscle cross talk. Furthermore, future studies should examine the muscle activity for the entire movement while wearing the weighted vest.

Additionally, to the researcher’s knowledge at the time of this study, there has been no other published work that has compared reaction times to simulated combat scenarios with and without wearing a weighted vest. Therefore, further comparisons of these conditions while performing other combative movements would help confirm the results of this study.

Repeating the study with a larger number of participants of similar disciplines and experience would further confirm the results of this study. Also, repeating the study and comparing different groups of subjects may lead to more useful information regarding weighted vest training vs. non-weighted vest training, or military occupation vs. law enforcement occupation, or comparison of completing the movements under different equipped conditions.

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Appendix A

Means and Standard Deviations for Reaction Time and RMS sEMG for each subject

Participant	Movement	RT (ms)	LO RMS (V)	LRA RMS (V)	RRA RMS (V)	RO RMS (V)	RT (ms)	LO RMS (V)	LRA RMS (V)	RRA RMS (V)	RO RMS (V)
1	L. Cross	257.2	0.23	0.12	0.36	0.33	317.4	0.12	0.15	0.10	0.47
	SD	57.2	0.21	0.07	0.27	0.19	34.3	0.12	0.20	0.03	0.20
	L. Dodge	284.8	0.50	0.29	0.07	0.14	345.0	0.43	0.50	0.08	0.12
	SD	83.4	0.09	0.18	0.01	0.09	68.3	0.18	0.20	0.02	0.10
	R. Cross	263.8	0.49	0.31	0.09	0.19	363.4	0.43	0.39	0.09	0.13
	SD	85.5	0.10	0.18	0.04	0.11	68.9	0.16	0.19	0.04	0.09
	R. Dodge	232.6	0.09	0.07	0.27	0.47	296.0	0.06	0.06	0.22	0.52
	SD	80.9	0.06	0.03	0.20	0.11	33.3	0.02	0.01	0.22	0.06
2	L. Cross	569.4	0.55	0.15	0.14	0.14	597.4	0.47	0.17	0.21	0.41
	SD	84.9	0.04	0.03	0.02	0.02	123.9	0.10	0.07	0.18	0.12
	L. Dodge	526.2	0.52	0.14	0.15	0.13	680.2	0.55	0.24	0.21	0.26
	SD	84.3	0.02	0.02	0.03	0.02	51.8	0.04	0.09	0.06	0.05
	R. Cross	550.6	0.50	0.21	0.37	0.25	614	0.42	0.17	0.23	0.46
	SD	107.8	0.07	0.03	0.15	0.09	41.1	0.13	0.07	0.16	0.10
	R. Dodge	517.6	0.36	0.15	0.35	0.40	572.4	0.29	0.14	0.14	0.55
	SD	61.2	0.23	0.04	0.15	0.23	91.4	0.03	0.03	0.03	0.03
3	L. Cross	426.8	0.34	0.41	0.46	0.25	537	0.26	0.49	0.42	0.24
	SD	46.0	0.09	0.12	0.12	0.01	73.6	0.07	0.06	0.12	0.02
	L. Dodge	473.8	0.46	0.53	0.30	0.27	609.6	0.24	0.52	0.32	0.22
	SD	55.1	0.08	0.08	0.06	0.05	94.3	0.01	0.02	0.10	0.01
	R. Cross	490.6	0.30	0.38	0.53	0.23	627	0.27	0.47	0.48	0.24
	SD	89.2	0.02	0.05	0.03	0.01	54.5	0.05	0.08	0.09	0.04
	R. Dodge	451.8	0.27	0.36	0.55	0.34	515.6	0.25	0.38	0.54	0.29
	SD	77.8	0.03	0.04	0.04	0.09	118.2	0.01	0.07	0.04	0.12
4	L. Cross	521.4	0.14	0.11	0.34	0.41	462	0.16	0.07	0.21	0.56
	SD	90.2	0.09	0.02	0.24	0.18	60.9	0.18	0.01	0.17	0.21
	L. Dodge	429.2	0.57	0.07	0.07	0.06	564	0.53	0.07	0.09	0.08
	SD	97.6	0.06	0.01	0.01	0.03	72.9	0.04	0.02	0.05	0.02
	R. Cross	466.2	0.33	0.28	0.11	0.09	456.4	0.21	0.15	0.46	0.13
	SD	49.6	0.25	0.24	0.10	0.02	51.4	0.18	0.20	0.16	0.05
	R. Dodge	473	0.17	0.11	0.33	0.43	571.8	0.08	0.08	0.29	0.39
	SD	58.6	0.08	0.03	0.20	0.15	32.9	0.02	0.04	0.21	0.21
5	L. Cross	362.4	0.35	0.08	0.07	0.41	327	0.19	0.44	0.30	0.07
	SD	95.3	0.22	0.01	0.01	0.28	90.7	0.07	0.32	0.23	0.03
	L. Dodge	276.2	0.39	0.34	0.13	0.21	368.8	0.19	0.60	0.22	0.07
	SD	40.9	0.21	0.25	0.14	0.19	116.7	0.13	0.13	0.15	0.03
	R. Cross	262.8	0.43	0.38	0.18	0.19	341.8	0.19	0.54	0.22	0.08
	SD	40.1	0.28	0.27	0.17	0.10	60.6	0.05	0.04	0.17	0.06
	R. Dodge	257.8	0.16	0.11	0.11	0.54	324.8	0.05	0.07	0.64	0.37
	SD	68.4	0.14	0.08	0.08	0.03	65.8	0.01	0.02	0.14	0.15
6	L. Cross	254.6	0.18	0.15	0.21	0.58	302	0.22	0.57	0.34	0.20
	SD	43.8	0.04	0.04	0.10	0.07	70.8	0.12	0.25	0.30	0.04
	L. Dodge	369.2	0.53	0.46	0.28	0.28	369.2	0.47	0.25	0.16	0.15
	SD	42.2	0.12	0.13	0.12	0.11	90.8	0.15	0.24	0.13	0.02
	R. Cross	268.6	0.27	0.22	0.33	0.44	286.2	0.44	0.42	0.07	0.20
	SD	71.0	0.09	0.12	0.19	0.15	91.3	0.16	0.25	0.01	0.11
	R. Dodge	234.8	0.13	0.18	0.19	0.58	261.8	0.07	0.09	0.47	0.50
	SD	30.4	0.01	0.08	0.09	0.08	69.8	0.03	0.06	0.12	0.31

7	L. Cross	311	0.13	0.07	0.07	0.58	353	0.08	0.07	0.41	0.31
	SD	119.9	0.03	0.01	0.01	0.09	45.5	0.02	0.02	0.29	0.18
	L. Dodge	307	0.53	0.11	0.12	0.30	345	0.56	0.13	0.10	0.17
	SD	85.9	0.02	0.04	0.11	0.13	73.7	0.01	0.09	0.02	0.09
	R. Cross	329	0.62	0.26	0.19	0.23	357	0.57	0.10	0.10	0.21
	SD	63.7	0.11	0.18	0.11	0.09	80.7	0.13	0.01	0.05	0.17
	R. Dodge	334.8	0.17	0.09	0.08	0.55	346	0.10	0.09	0.10	0.57
	SD	72.2	0.07	0.02	0.02	0.05	107.0	0.04	0.07	0.06	0.03
8	L. Cross	317	0.18	0.19	0.23	0.56	393	0.34	0.20	0.54	0.42
	SD	63.4	0.05	0.09	0.14	0.03	110.8	0.12	0.06	0.03	0.09
	L. Dodge	346	0.51	0.27	0.18	0.25	301.6	0.55	0.15	0.19	0.15
	SD	40.9	0.17	0.19	0.06	0.08	51.5	0.03	0.03	0.10	0.05
	R. Cross	294.2	0.27	0.21	0.25	0.53	331.2	0.51	0.43	0.25	0.20
	SD	61.3	0.08	0.15	0.19	0.02	53.0	0.12	0.18	0.12	0.12
	R. Dodge	270.8	0.20	0.19	0.15	0.54	318.8	0.19	0.36	0.41	0.58
	SD	58.6	0.05	0.06	0.03	0.04	47.9	0.05	0.13	0.04	0.05
9	L. Cross	345.6	0.48	0.30	0.14	0.26	352.4	0.47	0.31	0.14	0.25
	SD	59.8	0.21	0.28	0.08	0.10	107.5	0.23	0.27	0.04	0.12
	L. Dodge	320	0.52	0.20	0.17	0.12	321.8	0.53	0.10	0.07	0.21
	SD	35.1	0.12	0.19	0.13	0.07	34.0	0.04	0.06	0.02	0.12
	R. Cross	356.2	0.54	0.25	0.25	0.26	320.6	0.37	0.46	0.15	0.27
	SD	36.7	0.03	0.15	0.21	0.13	42.8	0.15	0.23	0.06	0.11
	R. Dodge	416.4	0.22	0.08	0.09	0.61	404	0.20	0.13	0.09	0.63
	SD	47.4	0.12	0.03	0.04	0.06	59.9	0.13	0.07	0.01	0.13
10	L. Cross	301.2	0.13	0.07	0.07	0.57	437	0.28	0.17	0.08	0.54
	SD	100.3	0.09	0.02	0.01	0.04	131.0	0.15	0.15	0.02	0.04
	L. Dodge	390.6	0.57	0.24	0.09	0.25	353.6	0.57	0.19	0.16	0.30
	SD	53.6	0.06	0.23	0.02	0.19	54.7	0.10	0.18	0.14	0.12
	R. Cross	309.6	0.58	0.08	0.08	0.12	412.6	0.51	0.23	0.17	0.26
	SD	51.5	0.05	0.03	0.02	0.04	73.5	0.15	0.22	0.06	0.11
	R. Dodge	267.6	0.13	0.13	0.13	0.53	400.4	0.17	0.11	0.19	0.56
	SD	68.1	0.10	0.12	0.13	0.03	119.1	0.12	0.07	0.18	0.07

Appendix B

Informed Consent

You are invited to participate in a research project conducted by graduate student Chris Banta of the Kinesiology Department at SUNY Cortland. He requests your informed consent to be a participant in the research project described below. The purpose of the research is to compare the reaction time and abdominal muscle activity while performing combative movements in a loaded and unloaded condition. Please feel free to ask about the project, its procedures, or objectives.

You will be performing four different combative movements in response to four visual stimuli which will be placed directly in front of you and behind a striking bag. The lead researcher will place four electrodes on the skin of your abdominals at four different locations to identify initiation of your movement after stimulus presentation and measure the electrical activity of the specific abdominal muscle involved in the movement. The anterior superior iliac spine (top-front of the hip) will be palpated for placement of two of the electrodes. Electrode placement will be adjusted if the presence of a skin irritant will be potentially aggravated. This electrical activity will be recorded using a Therapeutics Unlimited Model 544 Multichannel Electromyographic System as well as the Peak Motus® motion analysis system. The study will consist of three sessions that will last approximately an hour each. The first trial will familiarize you with the visual stimulus, movement while wearing a 10 kg weighted vest, and a short PARQ questionnaire about current physical activity, injury history, and demographic data. During the second and third sessions, you will complete 20 trials in either the loaded or unloaded condition. During each trial, the electrical signals detected by the electrodes will be recorded and stored for further analysis. Once the trials are completed you are free to leave.

The risks associated with your participation in this study are minimal. However, there is always a risk of injury associated with engaging in physical activity. In the unlikely occurrence an injury requires medical attention, SUNY Cortland Student Health Services will be contacted. The adhesive pads and medical tape may potentially cause skin irritation similar to a Band-Aid, but the conducting gel is non-allergenic. The bag gloves, weighted vest, and electrodes will be disinfected with rubbing alcohol prior to each use. Prior to the second and third session, you will need to have your abdomen area free of body hair and skin irritation (acne) so the electrode areas may be scrubbed with rubbing alcohol. You will indicate on the questionnaire that you understand the risks associated with physical activity, and are clear to participate in the study. Only the researcher will have access to your data. Your data will be stored on a flash drive containing your subject ID #. The data on the flash drive will be erased immediately following the completion of the study. Your data will also be stored on the hard drive of a desktop computer in the locked Biomechanics Lab (1163 Professional Studies Building). This data will be deleted 3 years after the completion of the study, upon which all files will be deleted. At no time will your name be associated with your data. You will be videotaped during the second and third sessions to identify any movements made that might result in unusual data found during the trial. The cameras will be placed behind you, so your faces will not be recorded. If no unusual data is found, the video recordings will be deleted.

You are free to withdraw consent and stop your participation in the project at any time without penalty. Additionally, at any time, you may ask the researcher to destroy all records of your performances, as well as any other data or information collected.

By participating in this study, you should expect to better understand the way in which research is conducted. Upon completion of your testing you will be given $15 gift card to Subway or similar fast food restaurant as a sign of thanks for your participation.

If you have any questions concerning the purpose or results of this study, you may contact Chris Banta at (315) 254-7405 or at christopher.banta@cortland.edu. Other contacts include: Dr. Jeff Bauer, Professor of Kinesiology at 1160 Professional Studies Building, or jeff.bauer@cortland.edu. For questions about research at SUNY Cortland or questions/concerns about participant rights and welfare, you may contact **the Institutional Review Board at SUNY Cortland**, PO Box 2000, Cortland, NY, 13045 phone (607) 753-2511 or email irb@cortland.edu).

I (print name) ____________________________________ have read the description of the project for which this consent is requested, understand my rights, and I hereby consent to participate in this study.

Signature: ____________________________________ Date: __________________

Appendix C

PAR-Q Data Collection Sheet

NAME: ______________________________________ DATE: ________________

HEIGHT: _________m. WEIGHT: ___________kg. AGE: __________

STUDENT NUMBER: __________________________ PHONE: _____________

EMAIL:____

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

	Questions	Yes	No
1	Has your doctor ever said that you have a heart condition and that you should only perform physical activity recommended by a doctor?		
2	Do you feel pain in your chest when you perform physical activity?		
3	In the past month, have you had chest pain when you were not performing any physical activity?		
4	Do you lose your balance because of dizziness or do you ever lose consciousness?		
5	Do you have a bone or joint problem that could be made worse by a change in your physical activity?		
6	Is your doctor currently prescribing any medication for your blood pressure or for a heart condition?		
7	Do you know of any other reason why you should not engage in physical activity?		

If you have answered "Yes" to one or more of the above questions, consult your physician before engaging in physical activity. Tell your physician which questions you answered "Yes" to. After a medical evaluation, seek advice from your physician on what type of activity is suitable for your current condition.

GENERAL RECREATION & MEDICAL QUESTIONNAIRE

	Recreational and Experience Questions	Yes	No
1	Do you partake in any recreational activities (golf, tennis, skiing, etc.)? (If yes, please explain.) ____ ____		
2	Do you have any hobbies (reading, gardening, working on cars, exploring the Internet, etc.)? (If yes, please explain.) ____ ____		

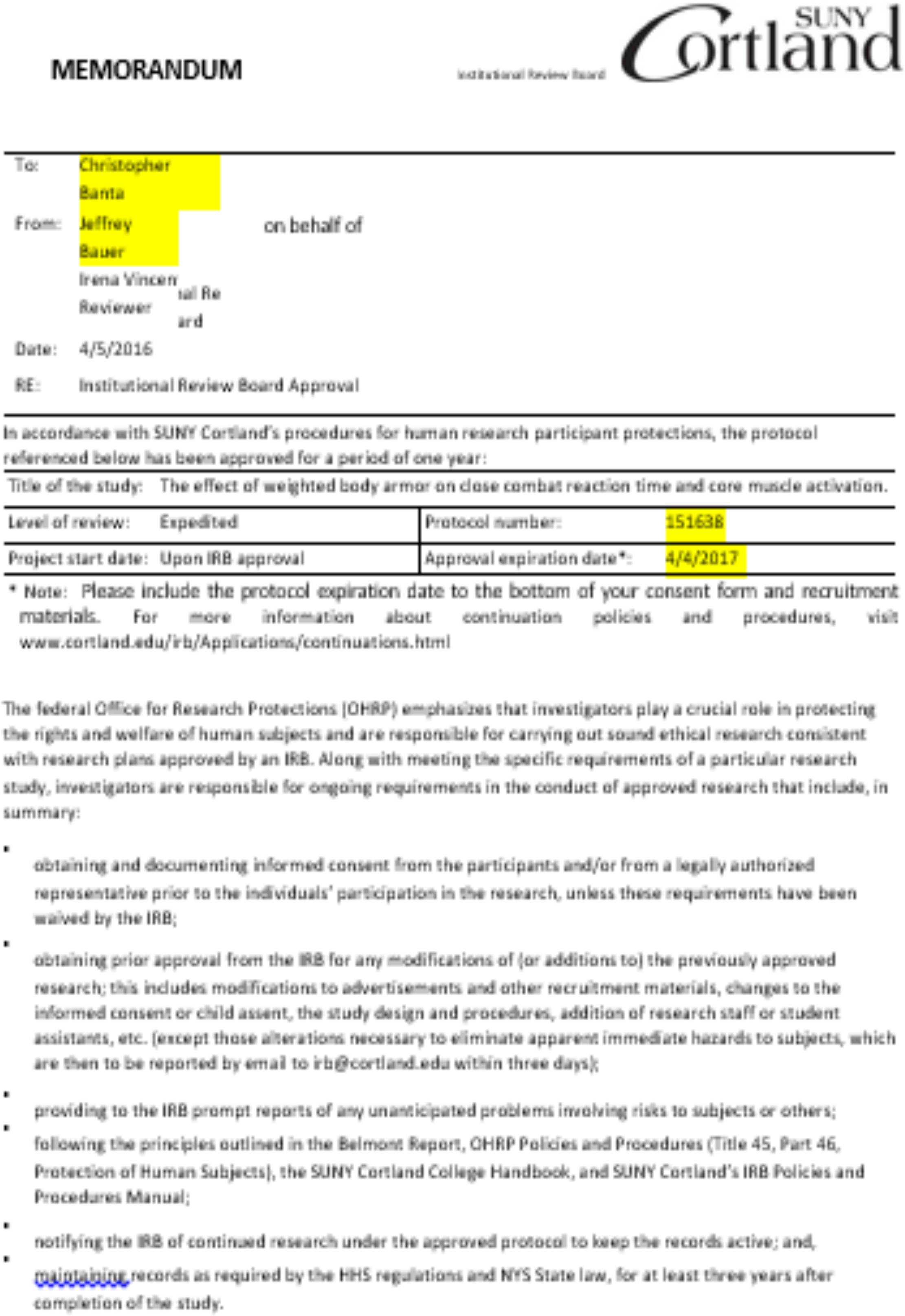
3	How many years have you participated in martial arts/boxing? What discipline(s)?	**xxxxxxxx xxxxxxxx xxxxxxxx xxxxxxxx**	**xxxxxxxx xxxxxxxx xxxxxxxx xxxxxxxx**
4	Do you have any military, law enforcement, or any other experience wearing a weighted vest? (If yes, please explain.)		
	Medical Questions	**Yes**	**No**
5	Do you have any pain or injuries (ankle, knee, hip, back, shoulder, etc.)? (If yes, please explain.)		
6	Have you had any surgeries in the past year? (If yes, please explain.)		
7	Has a medical doctor ever diagnosed you with a chronic disease, such as coronary heart disease, coronary artery disease, hypertension (high blood pressure), high cholesterol or diabetes? (If yes, please explain.)		
8	Has a medical doctor ever diagnosed you vision problems? (If yes, please list.)		
9	Do you have any skin allergies or any reason to believe that you would react to adhesives or rubbing alcohol placed on your skin? (If yes, please list.)		

I understand the risks associated with physical activity and declare that I am clear to participate

Signature

Date

Appendix D



MEMORANDUM

Institutional Review Board

SUNY Cortland

To: Christopher Banta
From: Jeffrey Bauer on behalf of
Irena Vincen ıal Re
Reviewer ard
Date: 4/5/2016
RE: Institutional Review Board Approval

In accordance with SUNY Cortland's procedures for human research participant protections, the protocol referenced below has been approved for a period of one year:

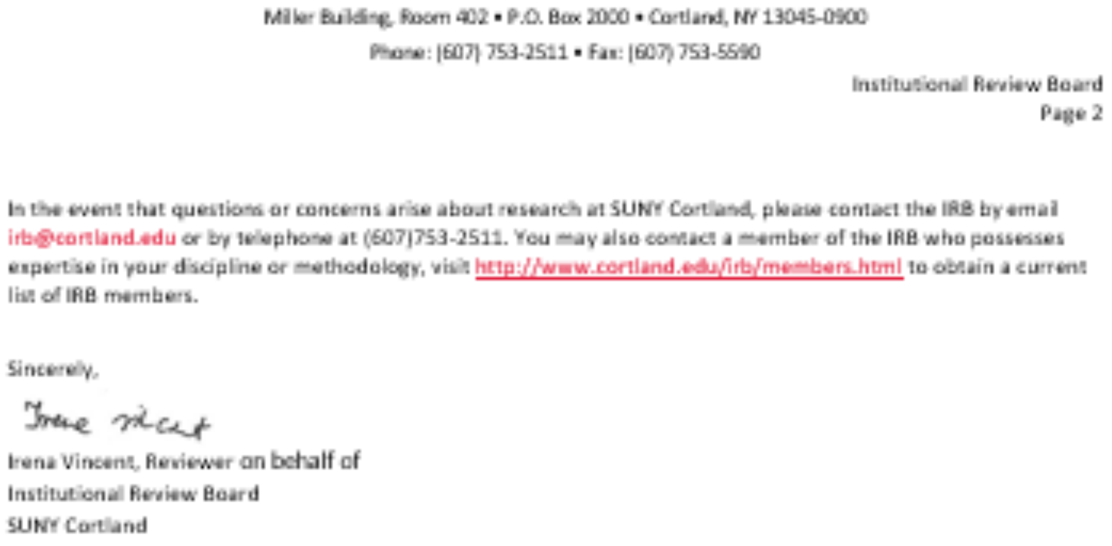
Title of the study: The effect of weighted body armor on close combat reaction time and core muscle activation.

Level of review:	Expedited	Protocol number:	151638
Project start date:	Upon IRB approval	Approval expiration date*:	4/4/2017

* Note: Please include the protocol expiration date to the bottom of your consent form and recruitment materials. For more information about continuation policies and procedures, visit www.cortland.edu/irb/Applications/continuations.html

The federal Office for Research Protections (OHRP) emphasizes that investigators play a crucial role in protecting the rights and welfare of human subjects and are responsible for carrying out sound ethical research consistent with research plans approved by an IRB. Along with meeting the specific requirements of a particular research study, investigators are responsible for ongoing requirements in the conduct of approved research that include, in summary:

- obtaining and documenting informed consent from the participants and/or from a legally authorized representative prior to the individuals' participation in the research, unless these requirements have been waived by the IRB;
- obtaining prior approval from the IRB for any modifications of (or additions to) the previously approved research; this includes modifications to advertisements and other recruitment materials, changes to the informed consent or child assent, the study design and procedures, addition of research staff or student assistants, etc. (except those alterations necessary to eliminate apparent immediate hazards to subjects, which are then to be reported by email to irb@cortland.edu within three days);
- providing to the IRB prompt reports of any unanticipated problems involving risks to subjects or others;
- following the principles outlined in the Belmont Report, OHRP Policies and Procedures (Title 45, Part 46, Protection of Human Subjects), the SUNY Cortland College Handbook, and SUNY Cortland's IRB Policies and Procedures Manual;
- notifying the IRB of continued research under the approved protocol to keep the records active; and,
- maintaining records as required by the HHS regulations and NYS State law, for at least three years after completion of the study.



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Phone: (607) 753-2511 • Fax: (607) 753-5590

Institutional Review Board
Page 2

In the event that questions or concerns arise about research at SUNY Cortland, please contact the IRB by email irb@cortland.edu or by telephone at (607)753-2511. You may also contact a member of the IRB who possesses expertise in your discipline or methodology, visit http://www.cortland.edu/irb/members.html to obtain a current list of IRB members.

Sincerely,

Irena Vincent, Reviewer on behalf of
Institutional Review Board
SUNY Cortland