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EFFECT OF LOAD CARRIAGE ON TACTICAL PERFORMANCE

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Education
at the University of Kentucky

By

Justin Matthew Thomas

Lexington, KY

Director: Dr. Mark Abel, Associate Professor of Kinesiology

Lexington, KY

2015

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ABSTRACT OF THESIS

EFFECT OF LOAD CARRIAGE ON TACTICAL PERFORMANCE

Special Weapons and Tactics (SWAT) operators are specially trained personnel that are required to carry equipment to perform high risk tasks. Given the need to carry this equipment, it is important to understand the potentially deleterious effect that the additional load may have on tactical performance. Furthermore, it is important to identify physical fitness characteristics that are associated with the potential decrement in performance. Therefore, the purpose of this study was to evaluate the effect of load carriage on tactical performance and identify fitness characteristics associated with any decrement in performance. Twelve male operators performed a simulated tactical test (STT) on a live firing range with (loaded condition) and without external equipment (unloaded condition) and completed a battery of physical fitness assessments. Time to complete the STT in the loaded condition increased by 7.8% compared to the unloaded condition. Nine of the 13 STT tasks were performed significantly slower in the loaded condition. VO_{2peak} was negatively associated and fatigue index was positively associated with the overall STT delta time. These findings indicate that a higher aerobic capacity and lower anaerobic fatigability are related to a greater resilience to carrying a load while performing tactical tasks.

KEYWORDS: Load Carriage, SWAT, Marksmanship, Tactical, Body Armor

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EFFECT OF LOAD CARRIAGE ON TACTICAL PERFORMANCE

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Chapter I: Introduction

According to the National Tactical Officers Association, “A special weapons and tactics (SWAT) unit is a designated law enforcement team whose members are recruited, selected, trained, equipped, and assigned to resolve critical incidents involving a threat to public safety which would otherwise exceed the capabilities of traditional law enforcement first responders and/or investigative units” (45). The purpose of SWAT units is to provide a systematic approach to tactical solutions with a priority to save lives and resolve critical conflicts effectively (45). SWAT operators perform a variety of physical tasks including sprinting, dodging, vaulting, crawling, lifting, and dragging (18). These tasks appear to utilize the full spectrum of physical fitness characteristics including aerobic and anaerobic endurance, muscular endurance, strength, and power (18).

SWAT operators are required to wear or carry various pieces of equipment for protection or in order to accomplish tasks. This equipment typically includes body armor, weapons, ammunitions, backpack, breaching tools, helmet, communications equipment, and medical equipment. Although many of these accessories are capable of protecting against injury, the ability to perform SWAT tasks may be compromised due to the added weight and the restrictive nature of the equipment. In general, load carriage reduces work efficiency while increasing physiological strain, perceived exertion, and risk of injury (7,20,49); therefore, it would seem logical that SWAT operators must maintain a high level of physical fitness to perform physical tasks in extreme situations while carrying tactical equipment. All of the items to be carried are specific to the individual mission, and are carried into hostile environments where the burden of the

added weight and restriction may have a negative influence on operator safety, performance, and mission success.

Previous investigations in other tactical populations have evaluated the effects of load carriage on operator performance (23,42,49,54). These studies have reported that load carriage has deleterious effects on a wide range of psychological, physiological and tactical outcomes including increased perceived exertion, decreased sprinting velocity, and decreased grenade throwing abilities (23,42,49). Furthermore, a recent study in Australian Army soldiers demonstrated a 31% decrease in a prone-to-sprinting maneuver when an additional 21.6 kg of gear was added to the soldier (55).

Unfortunately, there is a lack of research evaluating the effect of load carriage on SWAT operator performance. SWAT operators' load carriage requirement is unique as SWAT operators carry additional equipment compared to traditional law enforcement officers, yet do not carry ruck/back packs like many soldiers do. The tasks performed during tactical operations place unique physiological demands on the SWAT operator. Therefore it is important to understand the effects that SWAT equipment has on tactical performance. Furthermore, no research has evaluated the relationship between load carriage-induced performance decrements and physical fitness characteristics. This information is critical as it will guide the exercise prescription for SWAT operators to enhance their performance while performing tasks with tactical gear. Therefore, the primary purpose of this study was to evaluate the effect of load carriage on SWAT operator performance. The secondary purpose of this study was to determine which physical fitness characteristics were correlated to the performance decrement produced by the equipment. Based on previous literature, we hypothesized that there would be a

significant decrease in efficiency while performing a simulated tactical test (STT) in tactical gear compared to an unloaded control condition. Secondly, we hypothesized that the decrease in efficiency would be correlated to aerobic capacity, power output and maximal strength (31,48).

Delimitations

This study was delimited to the following factors.

1. The sample was composed of a single SWAT Unit from a moderate sized municipality in the southeastern United States.
2. Operators were males aged 23-41 years with 4.8 ± 4.6 years of experience as a SWAT operator.
3. Many of the SWAT officers in this study have a background in tactical competitions and therefore may represent a higher level of tactical performance than what is typical. Any generalizations made can only apply to SWAT officers of similar fitness and experience levels.

Assumptions

The following assumptions were made for this study.

1. The simulated tactical test replicated tasks performed during actual missions.
2. Operators provided a maximal effort on all physical assessments.
3. Questionnaire data provided to the primary investigator were true and accurate.

Chapter II: Review of Literature

Load carriage consisting of the tools to be used for a given mission is essential for the tactical operator. Load carriage is especially important for soldiers who often carry body armor and equipment in excess of 30-40% of their body mass (29). In 2007 it was reported that the average rifleman in Afghanistan had a fighting load of 29 kg; the average approach march load was 44 kg and the average emergency approach march load was 58 kg (6). A military fighting load would regularly consist of body armor, M4 carbine rifle with loaded magazine, combat boots, combat helmet, knee and elbow pads, goggles, folding knife, ammunition, 100 ounce hydration bladder, two quart canteens, bayonet, night vision equipment, fragmentation grenade, first aid equipment, flashlight, and compass. An approach march load would add additional weight due to a rucksack, increased water reserves, a 60mm mortar round, a poncho sack, ready to eat meals, a personal hygiene kit, clothing, intravenous fluids bag, rope with snap links, gun cleaning kit, and rubber gloves (7). According to the Army Field Manual, "Load carrying causes fatigue and lack of agility, placing soldiers at a disadvantage when rapid reaction to the enemy is required" (21).

Although of less magnitude, the 7-9 kg of personal safety equipment and accessories worn by law enforcement officers (e.g., armored vest, duty belt, side arm, etc.) results in significant physiological burdens to the user (5,42,20). It is of importance that the physiological effect of load carriage be considered when performing the wide variety of physical tasks necessary for law enforcement (18). This paper focuses mainly on the effects of load carriage within the special police service group called a Special Weapon and Tactics (SWAT) unit, however there has been little research conducted within this

population. The majority of relevant literature has been gathered from studies involving military and police.

Physiological Impact of load carriage

Research has shown that the added mass associated with load carriage can affect the physiological response and the biomechanics of the individual. The anatomical distribution of the load can have a significant impact as well (29,32,44). Carrying the load symmetrically around the waist and close to the center of mass causes the least metabolic perturbation to the whole body. Meanwhile, load carried on the extremities can further exacerbate the increase in energy expenditure as well as change the biomechanics of the individual. Compared with wearing a weighted vest, extremity armor has been shown to cause an increase in VO_2 during walking and running by about 7% and 17%, respectively (32). Energy expenditure differences can also be expected to change for the upper extremities as opposed to the lower extremities. Miller and Stamford (44) observed that per kilogram of weight added to the hand and ankle, a 13% and 8% increase in VO_2 was observed, respectively (44). The researchers also indicated that the caloric cost of walking with ankle and hand weights at the same time at $106.7 \text{ m}\cdot\text{min}^{-1}$ was similar to running at $134.1 \text{ m}\cdot\text{min}^{-1}$ without weights.

The increase in the physiological burden of load is especially apparent in the case of large military loads. In a study involving infantryman, Grenier et al. (29) observed that net walking energy expenditure increased by 42.5% when carrying a battle load (22.4 kg) and 70.8% when carrying a road march load (37.9 kg; 29). When compared relative to total mass (body mass + load), however, there was no significant difference in energy

expenditure due to load carried, meaning that the efficiency of walking was not reduced. This further indicates that the configuration or placement of the load has a great influence on the net energy expenditure of the individual (6,31).

Physiological responses, such as heart rate and VO_2 , have been observed to rise fairly linearly when walking with loads that increase from 0-70% of lean body mass (6,49). As load carried approaches higher relative percentages of an individuals' body weight, the more fatiguing a task becomes. Other factors have a large effect on the physiological strain of an individual as well, including speed of movement and grade of terrain. Ricciardi and colleagues (50) observed significantly increased heart rate, respiratory rate, VO_2 , and perceived exertion while walking at a slow ($61.7 \text{ m}\cdot\text{min}^{-1}$ [women] and $64.4 \text{ m}\cdot\text{min}^{-1}$ [men]) and moderate pace ($96.5 \text{ m}\cdot\text{min}^{-1}$ [women] and $101.9 \text{ m}\cdot\text{min}^{-1}$ [men]) at a 5% and 10% incline, respectively. These results were observed in operators wearing 10 kg of body armor. Wearing body armor was observed to account for significantly higher blood lactate values (6.7 ± 2.6 vs. $4.0 \pm 2.4 \text{ mmol}\cdot\text{L}^{-1}$) compared to no body armor condition.

Pulmonary function

An abundance of literature exists which attempts to elucidate the physiological consequences of load carriage on respiratory muscle fatigue. According to Brown and McConnell (11), "the implications of respiratory muscle fatigue in an occupational setting may extend to impairment of operational effectiveness, as well as the health and safety of employees." Faghy et al. (24) conducted a study involving 19 physically active males who completed two experimental trials (25 kg loaded vs unloaded). During each

condition the participant performed a 2.4 km timed trial on a treadmill as quickly as possible. Inspiratory and expiratory pressure immediately following exercise in the load carriage condition was reduced by 16% and 19%, respectively, compared to baseline. Inspiratory and expiratory pressure for the unloaded condition was reduced only 6% and 10%, respectively, compared to baseline. The authors suggest that load carriage presents a restriction to the chest wall, which exacerbates the challenges of exercise and acts to fatigue the respiratory musculature.

The reduction in pulmonary function is due, in part, to fatigue of the respiratory musculature and change in breathing mechanics. Research has shown that chest wall restriction can cause inspiratory volume limitations and diaphragm fatigue (17,25). In a study by Coast and colleagues (17), 18 operators performed 5 incremental maximal cycle ergometer tests. Varying levels of chest wall restriction was induced (0, 20, 40, and 60 mmHg) utilizing 2 fiberglass chest casts separated by inflatable cushions. A significant decrease was observed in VO_{2max} and time to volitional fatigue in nearly all conditions. At submaximal levels, VO_2 was not significantly different across restriction loads, however breathing frequency and tidal volume were significantly different across the restrictive loads at the submaximal level. The limitation that is placed on the ventilatory pump caused by load carriage is considered to have a similar effect as restrictions brought about by pulmonary disease.

Another mode of reducing operator performance during load carriage is through the respiratory muscle metaboreflex. Evidence has shown that diaphragm and abdominal muscle fatigue can elicit sympathetic vasoconstriction of the limb blood flow and induce locomotor muscle fatigue (11,22,51). Although during normal physiological conditions

the metaboreflex usually only occurs at high intensity exercise, it has been suggested that the influence of chest wall restriction and inspiratory resistance could cause this to occur at submaximal levels (11). A decrease in blood flow to the working muscle would likely cause an increase in perceived limb discomfort and fatigue along with a reduced exercise tolerance. Derchak et al. (22) evaluated the effect of two different resisted expiration protocols (long expiration vs. short expiration) on sympathetic nerve activity in six men (22). Sympathetic nerve activity (via the right peroneal nerve) did significantly increase within the limb but only during the second or third minute of high intensity expiratory muscle work. It is suggested that the metaboreflex response is attributed to the ischemia and metabolite production of the expiratory musculature. This accumulation is thought to be a determinant in sympathetic stimulation and whole body blood flow distribution affecting limb musculature. Taylor et al. (54) evaluated the effect of three exercise conditions on healthy male operators. Each operator performed constant load cycle exercise on an electromagnetically braked cycle ergometer at 90% peak power output. Three exercise conditions were induced: prior expiratory muscle fatigue, no prior expiratory muscle fatigue, and time matched (no expiratory muscle fatigue induced but participant exercised the same duration as the expiratory fatigue trial). Operator exercise tolerance was reduced by 33% in the expiratory muscle fatigue condition compared to no prior fatigue. Also, gastric pressure response to thoracic nerve stimulation and quadriceps twitch force (measured 4 min post-exercise) was further reduced in the expiratory muscle fatigue condition versus the time matched condition without prior fatigue. Perceptions of leg discomfort and dyspnea were rated higher during and following exercise after expiratory muscle fatigue compared to the time matched without

prior fatigue. The authors postulated that the perceived limb fatigue arose from sympathetically mediated vasoconstriction causing a lack of blood flow and greater muscle fatigue and impairment of the limbs.

Impact of load carriage/body armor on performance

Tactical operators are required to carry supplies and personal protective equipment in load carriage systems. This load results in consequences to the musculoskeletal and metabolic system of the individual and decreases operational performance. As Beekley et al. (6) stated, "Increases in metabolic cost do not come without penalty. It affects how fast soldiers can move, inhibits movement over obstacles, affects how fatigued soldiers are upon arrival, increases caloric needs, and increases the risk of injuries" (6). The outcome of a mission is heavily dependent on the ability of the tactical soldier to be able to quickly and effectively traverse the environment. For a soldier within a hostile environment, quick, explosive movements are critical in order to avoid enemy fire. Even for law enforcement during routine traffic stops on busy highways or during interactions with potential suspects, quick movements are critical for the success of the operation and safety of the officer. The first few movements can have a dramatic impact on a scenario. The movements that can allow an officer to close the gap between themselves and a suspect in order to disarm and neutralize can also allow an officer to evade attacking suspects and draw their weapon for defensive purposes. These quick bursts of movement are particularly sensitive to the negative effect of load carriage (42,55). Lewinski and colleagues (42) investigated the effect of wearing a 9.07 kg weight belt on the first six strides of a short sprint. The sprints were performed from 4 starting positions: forwards, backwards, 90 degrees left and 90 degrees right. The primary finding was that excess

weight carried by operators resulted in 5% decrease in sprint stride velocity and acceleration. The researchers attribute their results to an increase in ground contact time that likely increased eccentric loading which, in turn, overloaded the muscles during the stretch-shortening cycle.

Various studies have evaluated the effect of load carriage on an individual's ability to negotiate obstacles (23,28,32). Performance on an obstacle course can be helpful in representing movements and challenges similar to that of the scenarios frequently encountered during a typical mission, whether that be traversing a battlefield or disarming a suspect (28). According to the US Army field manual on foot travel, the time it takes a soldier to complete an obstacle course is increased by 10-15% for every 4.5 kg of load carried (21). Frykman et al. (28) observed the completion times of an obstacle course by 11 female US Army soldiers (28). On average it took 47.7% longer to complete the total course when the volunteers were wearing 27 kg of load versus 14 kg. Some of the volunteers weren't even able to complete select obstacles when in the 27 kg condition. In a study designed to assess the influence of body armor on task elements involved in policing, Dempsey and colleagues (20) investigated the effect that stab resistant body armor and associated equipment had on the physiological responses and performance of operators during simulated mobility tasks (balance task, grappling task, acceleration from sitting, chin-ups, and push-up position maneuverability task). The 7.65 kg of body armor negatively impacted the wearer, resulting in performance decrements from 13%-42%. Also, all mobility tasks were significantly slower following a 5-min run (representing an abrupt pursuing movement).

Military combat loads are carried for much longer durations over longer distances. The loads can be significantly heavier due to the dynamic nature of the operations, as well as the fact that the soldier must carry enough equipment to complete the mission and to sustain himself throughout. History has proven that changes in warfare (mainly technology) cannot be relied upon to lessen the burden of load carried by the soldier. Often, the technology that is applied to reduce the soldier's load is counterbalanced with an increase in load elsewhere (47). For example, recently more than a half billion dollars were used to fund research of a high tech system for U.S. soldiers called the Land Warrior. This technology would allow a soldier to track friendly and enemy forces by flipping down an eyepiece located on the helmet (7). The original model weighed more than 9 kilograms with batteries included and created quite a hindrance on the back. Slimmer, lighter versions have been developed since.

Current literature on military load carriage has a primary focus on long distance marching. As would be expected, the time taken to cover a given march distance is increased as load is increased (35,38). Two operational loads are considered during long military marches; that is the approach march load and the fighting load. According to Army Field Manual, the Army approach march load is not to exceed 33 kg and the fighting load is not to exceed 22 kg. However, an emergency approach march load can demand up to 54 kg be carried (21). A study by Johnson and colleagues (35) investigated the effect of increasing load carriage (34, 48, and 61 kg, respectively) on performance and exertion while performing a 20 km road march. Load was carried via a standard issue U.S. Army backpack. Fatigue and muscle discomfort became more intense while alertness and feelings of well-being became less intense as the mass increased. A

significant increase in time to complete each trial was observed as mass was increased (171, 216, 253 min, respectively; $p < .001$).

Marksmanship

Lethality can come in many forms for a tactical operator. For this study we considered the effect of load carriage on marksmanship. There is a dearth of literature available on this topic. In a study by Carbone and colleagues (13), marksmanship was investigated in both static standing and following a mobile task (13). The officers engaged a target at a distance of 6 m with a 9 mm Glock pistol in two different conditions, unloaded and tactically loaded (22.8 kg). Mean values showed a general improvement in marksmanship when tactically loaded, although only the X-axis dispersion measure showed significance ($p = 0.047$). This result would indicate that given the load and training status exhibited by the tactical operations officer in this study, being tactically loaded does not reduce but may improve marksmanship at close range. It has been suggested that a potential stabilizing effect of body armor combined with consistent load carriage training can contribute to the effect observed in the study (13,14).

Physical Conditioning for Load Carriage

Literature has suggested that physical conditioning can be essential to increase an individual's resilience to the negative effect of load carriage (47). The outline of the training must consider intensity (load and speed), frequency (days per week) and volume (duration) (46).

In order to more safely and efficiently manage load carriage a training program must include activities that will translate into actual performance and take into account

operational movement patterns. As with training any athlete, the principle of specificity is a crucial aspect of training that must be included. Since any tactical task will be carried out with the burden of gear, training prescription should include load carriage components occurring at a predetermined frequency. If load training sessions are too infrequent, detraining will occur. If training sessions are too frequent, little recovery will likely lead to injuries and/or overtraining. A conditioning program involving a load carriage training session every 7-14 days is optimal (30,46). A study by Knapik et al. (37) observed a faster time for a 20 km march when load march training occurred twice a month compared with only once monthly. However, there was no difference between the group that trained twice per month versus the group that trained 4 times per month (37). Similarly, a study by Harmen et al. observed a significantly faster 3.2 km load carriage hike time when a progressive load was carried once each week for 24 weeks (30). Speed and distance were held constant and the load was progressively increased throughout the study. The speed at which a 34 kg backpack could be carried over a mixed-terrain course increased from 91.7 to 118.3 meters per minute.

Many physical training modes have been investigated to improve load carriage performance: aerobic endurance, aerobic interval, total body resistance, upper body resistance, lower body resistance, plyometric, calisthenics, load carriage activities, and a combination of multiple training strategies. Kraemer and colleagues (40) stated that “concurrent training is important and possibly necessary to achieve improvement for this type of task [load carriage].” In the study by Kraemer et al. (40), four conditions were observed: An endurance trained group, a resistance trained group, an endurance and total body resistance trained group, and an endurance and upper body resistance trained group.

Their findings showed that only the two groups participating in concurrent resistance and endurance training had a decrease in time to complete a 3.2 km march/run while loaded (44.7 kg). However, contribution of upper and lower body strength to load carriage performance remains unclear. A second study by Kraemer et al. (39) also indicated that although resistance and aerobic training resulted in a significant increase in load bearing task performance, no significant difference was observed between the upper body and total body resistance trained group. This finding suggests that upper body resistance-aerobic training is as effective as both upper and lower body resistance-aerobic training. Therefore it would seem that upper body musculature is more important to load carriage performance than lower body musculature during a road march task.

Summary

Load carriage increases physiological stress and negatively impacts operator performance. This increase in stress exacerbates the challenging nature of tactical operations by reducing mobility and task efficiency of the operator. However, given the appropriate training, load carriage may improve marksmanship at close range. An operationally designed conditioning program is important to attenuate the negative effects of load carriage. Furthermore, the program should include a load carriage activity performed at a sufficient frequency, as well as aerobic and resistance training.

Chapter III: Methodology

Experimental Approach to the Problem

To evaluate the effect of load carriage on SWAT operators' performance, a quasi-experimental case-control design was utilized. During the load carriage condition the operators' "normal" tactical attire and gear were utilized. Only minimal gear was used in the unloaded conditioning (i.e., physical training clothing). For the primary analysis, the independent variable was the load carriage condition. The dependent variables were the performance outcomes on the STT (total completion time, individual task time, shooting accuracy, heart rate, blood lactate, & rating of perceived exertion). For the secondary analysis, when identifying fitness correlates to performance decrements the physical fitness characteristics served as the independent variables and the STT delta score (change in time between conditions) was the dependent variable.

Subjects

A convenience sample of SWAT operators from a local Police Department was recruited to participate in this study. The police department is located in a mid-sized metropolitan area in the southeastern United States. All operators provided written informed consent prior to participation in this study. The study was approved by the University's Institutional Review Board prior to recruitment of operators or data collection. Exclusion criteria for the study included diagnoses of a physical injury that would not permit operators to perform the physical aspects of this study. Seventeen operators volunteered to participate in the study. Of the 17 operators, 13 participated in the follow-up fitness testing. One operator was excluded from the data analysis due to

committing several technical errors on the STT, thus resulting in a total of 12 operators. Table 1 displays the demographic and physical characteristics of the operators.

Table 1. Basic demographic characteristics of 12 male SWAT operators.

	Mean	±	SD
Age (yr)	33.7	±	5.2
Height (cm)	182.2	±	6.6
Body mass (kg)	92.7	±	12.9
Law enforcement experience (yr)	8.8	±	4.4
SWAT experience (yr)	4.8	±	4.6

Procedures

Basic demographic data were collected regarding military and occupational experience to account for potential relationships that may influence physical ability and marksmanship in a loaded condition. Thus, each operator completed a questionnaire and provided information regarding occupational rank, and years of experience in law enforcement, the military, and on the SWAT unit. The operator also provided information regarding recent exercise behavior, such as exercise frequency ($d \cdot wk^{-1}$) and intensity. Intensity was measured in the following scale: 0 = light, 1 = light to moderate, 2 = moderate, 3 = moderate to vigorous, 4 = vigorous.

Physical Fitness Assessments

The SWAT operators performed a battery of physical fitness tests to assess aerobic and anaerobic endurance, muscular endurance, strength, power, agility, flexibility, and

body composition. In addition, each participant completed an obstacle course that was designed to simulate tactical tasks. The sequence of tests performed within a given session was arranged from least to most fatiguing to minimize the effect of fatigue on subsequent tests. Table 2 displays the composition and order of testing sessions used in this study. At least 2 days of recovery was provided between testing sessions.

Table 2. Composition of testing sessions and order of physical fitness tests for SWAT operators.

Testing Session	Assessment
1	Anthropometrics, Submaximal GXT, Agility, Vertical peak power, Upper body muscle endurance, Anaerobic capacity, and Flexibility, Trunk endurance
2	Upper and lower body strength
3	Familiarization of the STT (1 practice trial)
4	Official trials on the STT (Load carriage and unloaded trials)

GXT: Graded exercise test; STT: Simulated tactical test.

Anthropometric Measurements

The operator’s body mass was measured (to the nearest 0.1 kg) without shoes with a digital scale (Teraoka Weigh-system, Model DI-10, Concord, ON). Standing height was measured (to the nearest 0.1 cm) without shoes with a wall mounted stadiometer (Seca, Hanover, MD). The operator’s abdominal, hip and waist circumference were measured with a flexible tape measure according to ACSM’s

guidelines. The abdominal measurement was taken at the level of the umbilicus. The waist measurement was taken at the narrowest part of the torso. The hip measurement was taken at the maximal circumference of the buttocks. Duplicate measurements were obtained at each site in a rotational order until two measures were within 5mm. An average of the two measures was used in the analysis. Body composition was measured with a whole body bioelectric impedance analyzer (Biodynamics Model 310 Body Composition Analyzer, Seattle, WA). Specifically, four surface electrodes were placed on the operators' right wrist, hand, ankle, and foot. The operators were instructed to lie supine for approximately 5 minutes before the impedance measurement was made. The operator's height and body mass were entered into the device to allow for the calculation of resistance at 4 different frequencies (5 kHz, 50 kHz, 100 kHz, and 200 kHz). Then, the resistance for the 50 kHz frequency was entered into the following formula for fat free mass (52):

$$\text{FFM (kg)} = 0.00066360 (\text{HT}^2) - 0.02117 (\text{R}) + 0.62854 (\text{BW}) - 0.12380 (\text{age}) + 9.33285$$

FFM: Fat-free mass; HT: Height measured in cm; BW: Body weight measured in kg;

Age: measured in years.

The correlation coefficient for this equation was $R = 0.956$ and the $\text{SEE} = 2.47$ kg. The value for fat-free mass was then utilized to calculate body fat percentage and subsequently used in the statistical analysis.

Upper and Lower Body Strength

Upper body maximal strength was assessed using a 1 repetition maximum (1RM) assessment of the barbell bench press exercise. The operator was instructed to slowly lower the bar, touch the chest, and fully extend the arms. A warm-up was performed

with a resistance that easily allowed 5 to 10 repetitions. A 1-minute rest period followed. Then, by adding 4.5 to 9 kg, a warm-up load was estimated that allowed the operator to complete 3 to 5 repetitions. A 2-minute rest period followed. Then, by adding 4.5 to 9 kg, a near maximal load was utilized that allowed the operator to complete 2 to 3 repetitions. A 2 to 4-minute rest period followed. The load was then be increased by 4.5 to 9 kg and the operator attempted a 1RM. If the operator was successful with the lift, another load increase followed (4.5-9 kg). If the operator was unsuccessful with the lift, the load was decreased by 2.25 to 4.5 kg and another 1RM was attempted. The load continued to increase or decrease until the operator could complete one repetition using proper technique (2,43). In addition to absolute strength, relative upper body strength was utilized in the analysis as well ($1\text{RM}\cdot\text{Body mass}^{-1}$).

Lower body strength was assessed using an incline leg press machine. The test began with a warm-up set using a resistance that easily allowed the operator to complete 10 repetitions. After one minute of recovery, the operator performed ten repetitions of 60-80% of the estimated 10-RM. Following this set and the sets thereafter, 3 to 5 minutes of rest was provided. The maximal load successfully lifted and the number of repetitions performed were recorded. The 1-RM leg press value was estimated using the following equation (24): $1\text{ RM} = (1 + 0.0333 \cdot \text{repetitions}) \cdot \text{repetition weight}$). This prediction equation has demonstrated a high degree of validity in previous research involving similar lower body exercises ($\text{ICC} = 0.968$; 41). In addition to absolute strength, relative lower body strength was utilized in the analysis as well (Estimated $1\text{RM}\cdot\text{Body mass}^{-1}$).

Vertical Peak Power

A vertical jump test was performed to assess lower body peak power. The test-retest reliability of this assessment within this sample was $ICC = .98$. This test was performed using a Vertec™ apparatus (Vertec Scientific Ltd., Aldermaston, UK). The operator was instructed to reach and touch the highest vane with the dominant arm while standing flat-footed. Then the operator performed a countermovement by flexing the knees and hips and swinging the arms followed by an explosive two-foot jump. Approach steps were not allowed. Using the dominant arm the operator reached upward and touched the highest vane possible. Vertical jump height was calculated as the difference between the vertical jump height and reach height values (measured to the nearest 1.3 cm). Two practice trials were performed, followed by three official trials. The highest value of the official trials was used in the analysis. To account for differences in operators' body mass, the vertical jump height value was divided by the operators' body mass to create a relative vertical jump power output value.

Cardiorespiratory Fitness

A submaximal treadmill protocol was utilized to estimate cardiorespiratory fitness. This is a valid field assessment ($R^2 = .33$, $SEE = 5.20 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) that was developed using a tactical population (53). The test began with a warm-up period of 3 minutes at a speed of $94 \text{ m}\cdot\text{min}^{-1}$. After the warm-up, the treadmill speed was increased to $120 \text{ m}\cdot\text{min}^{-1}$. Then, every 60 s, the speed and grade increased in an alternating manner by $13 \text{ m}\cdot\text{min}^{-1}$ and 2%, respectively. The time to reach 85% of predicted maximal heart rate

$(208 - (0.7 \times \text{age (yr)}) \times .85)$ was recorded (53). The following equation was utilized to estimate $VO_{2\text{peak}}$:

$$\text{Peak } VO_2 = 56.981 + [1.242(\text{time})] - [.805(\text{BMI})]$$

VO_2 is expressed in $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$; Time: duration (min) of the protocol. BMI: Body mass index

Agility

The Illinois Agility Test was utilized to assess agility (36). The test schematic is described elsewhere (36). The test-retest reliability of this test in this sample was $\text{ICC} = 0.97$. A stopwatch was used to measure the trial duration. The operator completed a standardized dynamic warm-up led by the researcher. The operator began the test in a prone position at the start line. The test began, and time started, upon the first movement of the operator at which point the operator jumped to their feet and navigated the cones (36). Two trials were performed with three minutes of recovery provided between trials. The fastest time was used in the data analysis.

Upper Body Muscle Endurance

Upper body muscle endurance was measured by performing a maximal push-up test. This test protocol has been utilized in research with similar tactical populations (5). The operator began the test by maneuvering into a prone position with hands placed directly under the shoulder and arms fully extended. The test was initiated as the operator lowered his body until his chest touched a 7.6 cm sponge. The sponge was used to standardize the downward position for all operators and is common practice in police academy physical fitness testing (5). The operator was instructed to avoid touching stomach or thighs to the mat while in the down position. There was no rest time or time

limit for this test. The test was terminated when the operator reached failure or was no longer able to maintain proper form. Number of consecutive push-ups were recorded.

Trunk Endurance

Lower back muscle endurance was measured using a modified version of the Biering Sorensen Test of Static Muscle Endurance. This isometric test has been reported to be a valid measure of trunk endurance and predictor of future lower back pain occurrence (1,8,19). Investigators have found the reliability to be satisfactory (ICC > 0.75;19). The duration of time that the operator was able to maintain the upper torso in a horizontal, erect position was evaluated. The operator's hips and legs were fastened to a table by three straps. Beginning at the iliac crest, the upper torso was to remain unsupported, off of the table. Observation of the horizontal position was conducted by using a reference marker suspended above the operator's upper back between the shoulder blades. The test began when operator established the extended position and made contact with the reference marker. One warning was given when the operator lost contact with the marker. When loss of contact occurred a second time the test was terminated. Duration until the operator reached their tolerance was recorded (8).

Anaerobic Capacity

A measure of anaerobic capacity was evaluated with a Wingate Anaerobic test (WAnT). Test-retest reliability of this assessment has been reported to be ICC = 0.98 (56). A MonarkTM cycle ergometer was utilized. The resistance placed on the flywheel was standardized relative to the operator's body mass and set at 7.5% of body mass as suggested in previous research (3). The test consisted of the following intervals: A warm-up, a recovery interval, an acceleration interval, a 30 sec all-out effort, and a cool-

down period (4). Outcome variables for the WAnT were peak power, mean power, and fatigue index. Relative peak power was the greatest power output ($\text{W}\cdot\text{kg}^{-1}$) recorded during any of the 5 second sampling periods. Relative mean power was recorded as the average power output ($\text{W}\cdot\text{kg}^{-1}$) during all of the 5 second intervals throughout the 30 second test. Fatigue index was calculated as the percent decrease in power from the highest power to the lowest power observed throughout the entire test (4).

Flexibility

The Sit and Reach Test was utilized to measure lower back and hamstring flexibility with the Acuflex I apparatus (Novel Products Inc., Rockton, IL). The sensitivity of the apparatus is 1 cm. The test-retest reliability of this assessment in this sample was $\text{ICC} = 0.99$. The operator removed their shoes and sat on the floor with legs extended. The feet were placed against the testing apparatus. The medial aspect of the feet were positioned 20 cm apart. The operator overlapped their hands such that the finger tips were aligned. The operator was instructed to exhale and reach as far forward as possible and hold that position for 2 seconds. Two practice trials were provided. The greatest measurement taken for the three official trials was utilized in the data analysis.

Simulated Tactical Test

A simulated tactical test (STT) was designed by an expert informant (Training Officer) that included tasks that simulate duties typically performed by SWAT operators. To account for a potential familiarization effect, the operators performed 1 practice trial of the STT in the loaded condition on a separate day. The reliability of performance on the STT was $\text{ICC} = 0.91$ based on the practice trial and the official loaded trial. These two conditions were used in the reliability analysis because both conditions required the

operators to wear full gear. Due to scheduling limitations, each operator completed the loaded and unloaded conditions of the STT on the same day. The loaded trial was completed with the gear that the operator would typically wear during a SWAT mission. This gear included a vest with ballistic armor, helmet, duty belt, weapons, ammunitions, communications equipment, and medical equipment. The average mass of the equipment was 14.2 ± 2.0 kg. The other trial was performed without gear and in preferred physical training attire. The order of the two trials was randomized and counterbalanced. The time to complete each task and shooting accuracy were recorded. During the loaded condition, both the AR-15 weapon and the Glock 35 handgun were carried throughout the majority of the course. For the unloaded condition only, the handgun was staged at the handgun shooting position, and was therefore not carried throughout the course as it was considered part of the operators' equipment. The rifle was staged at the first shooting task for both conditions.

The operator initiated movement on the researcher's command. The first task required the operator to ascend a flight of 18 steps (height: 18.4 cm; depth: 27.9 cm), run 3.2 m around a door frame, and descend the same flight of steps. The stair split time for the stair ascent/descent task was recorded when the operator's feet touched the ground after the final step. Next, the operator ran 44 m and scaled a 1.5 m wall. The split time for the wall scale task was taken when the operator's feet touched the ground on the opposite side of the wall. Next, the operator proceeded 4.6 m to a barrel, picked up a staged AR-15 weapon and fired 5 rounds from a standing position at designated target "A", located 37 m away. The split time for the barrel shooting task was taken when the fifth round was fired. Next, the operator advanced 14 m to a 3 tier obstacle where 5

rounds were fired over the top of the obstacle from a standing position with the AR-15 and 5 rounds were fired from a prone position at designated target “B”, located 23 m away. The 3-teir shooting task time was taken upon firing the fifth round from the prone position. The operator then stood up and accelerated 14 m to complete an up-and-go task. Next, the operator ran 10 m to a cone, turned 90° and proceeded 10 m to complete the agility task. Next, the operator advanced 5.5 m and performed a low crawl task. Specifically, the operator performed a prone “army crawl” for 4 m under a 0.6 m obstacle. The split time for the low crawl task was taken when the operator stood up on the opposite side of the obstacle. Next the operator proceeded 17 m to another 3-teir obstacle and used the AR-15 weapon to fire 5 rounds from a seated position at designated target “C”, located 14 m away. The split time for the seated shot task was taken when the fifth round was fired. Next, the operator ran 33 m, placed the AR-15 on the ground, picked up a battering ram (mass: 19.1 kg) and carried it 30.8 m to the location of a door-breaching obstacle. The operator used the ram to breach the door. Once the door was open, the operator entered the staged door and placed the ram on the ground. The split time was taken for the door breach task once the ram was placed on the ground. The operator proceeded 8.2 m and fired a handgun (Glock 35, .40 caliber) at 6 circular steel targets (diameter: 20.3 cm). The split time for the handgun task was taken when the sixth target was knocked down. Next, after advancing 14 m, a victim rescue task was performed. Specifically, the operator used their preferred lifting technique to grasp a rescue mannequin (84 kg) and drag it 23 m. The split time for the victim rescue task was taken when the heels of the mannequin crossed the 23 m line. Finally, the operator performed a sprint task. Specifically, the operator picked up the AR-15 weapon and

sprinted 34.7 m to the finish line. The sprint split and overall course times were taken when the operator reached the finish line. The overall distance of the course was 265 m.

Upon completion of the STT, each operator was asked to rate the overall relevancy of the course compared to the tasks actually performed on a tactical mission. A Likert-type categorical, ordinal scale was utilized for the responses as follows: 1 = Not relevant, 3 = Somewhat relevant, 5 = Very relevant. The median value for the rating of relevancy was a 4 (range: 3-5).

Blood lactate was measured prior to beginning the official trials (loaded & unloaded), and five minutes after each trial. The calibration of the blood lactate analyzer (LactatePlus, Nova Biomedical Corporation, Waltham, MA) was checked using two solutions of known lactate concentrations (high concentration: 4.0-5.4 mmol·dL⁻¹; low concentration: 1.0-1.6 mmol·dL⁻¹). Rating of perceived exertion (RPE) for the STT was measured immediately following the STT using a 15-point category-ratio scale (6-20) (10). In order to observe the cardiovascular demand of the obstacle course the operators wore a heart rate monitor around their chest, placed directly on the skin. An ActiTrainer (ActiGraph Inc, Pensacola, FL) device was placed in a neoprene sleeve around the operators' upper arm to record heart rate. The recording device tracked the number of heart beats per 15 second epoch. The device's internal clock was synchronized to a personal watch and computer in order to ensure that the appropriate heart rate data were paired with each operator. The heart rate data were downloaded to a personal computer using the manufacturer's software (ActiLife, Version 5, ActiGraph Inc, Pensacola, FL) and exported to a spreadsheet for analysis. Specifically, the number of myocardial contractions per 15 second epoch was multiplied by 4 to extrapolate the heart rate per

minute. Then, the 15 s heart rate extrapolations were averaged for the duration of the trial.

Marksmanship

Each target represented the silhouette of a person and contained a 25 mm disc located at the widest portion of the upper torso (as instructed by the expert informant). Shooting accuracy as well as horizontal and vertical displacement were measured, as described elsewhere (14). Shooting accuracy was calculated by measuring the average distance of the sum of all shots for each target (to the nearest mm). The horizontal displacement was measured as the distance between the furthest two horizontally displaced shots. The vertical displacement was measured as the distance between the furthest two vertically displaced shots. The values for horizontal and vertical displacement were used to further describe marksmanship results and to explain the potential axis influencing any changes in accuracy.

Statistical Analysis

Basic statistics (mean \pm standard deviation) were used to describe demographic, physical fitness, and performance data. The normality of primary outcome variables' distributions were assessed with Fisher's skewness coefficient (Coefficient = skewness / standard error of skewness). Paired sample t-tests were used to compare the STT times (individual tasks and overall completion time), shooting accuracy, heart rate, blood lactate and RPE outcomes between control and load carriage conditions. For each task a difference score was calculated (loaded task time – unloaded task time; i.e., delta time). One of the operators performed 3 of the STT tasks incorrectly and was therefore excluded from the statistical analysis. A second operator performed only one of the tasks

incorrectly (minor deviation) and was retained in the statistical analysis. Bivariate correlations were then used to assess the relationship between the STT delta scores and physical fitness outcomes. To control for the inflation of Type I error due to utilizing multiple t-tests, the level of significance was conservatively reduced to $p < .01$ for paired sample T-tests and set at $p < .05$ for regression analyses. The Statistical Package for Social Sciences (SPSS, Version 21) was used to analyze data.

Chapter IV: Results

Comparisons of STT times in the loaded versus unloaded conditions are displayed in Table 3. SWAT operators completed the STT significantly slower in the loaded condition compared to the unloaded condition. Of the 13 STT tasks, 9 were performed significantly slower in the loaded condition. Three of the four shooting task times were similar between loaded and unloaded conditions. The seated shot task was performed significantly slower in the loaded condition.

Table 3. Comparison of simulated tactical test task times in unloaded and loaded conditions in 12 male SWAT operators.*

Task	Unloaded STT (s)	Loaded STT (s)	Absolute difference (s)	% Change	<i>p</i> Value
Total time	191.4 ± 21.3	206.3 ± 23.8	14.9	7.8	<.001
Stair climb	9.6 ± 1.0	11.0 ± 1.3	1.4	14.0	<.001
Wall climb	11.0 ± 1.2	12.8 ± 1.6	1.8	16.7	<.001
Barrel shot	18.4 ± 2.0	19.7 ± 2.8	1.2	6.7	.116
Standing/prone shot	38.4 ± 5.3	37.6 ± 6.7	-0.8	-2.1	.700
Up-and-Go	5.5 ± 0.7	6.3 ± 0.7	0.7	13.5	<.001
Agility	5.0 ± 0.5	5.5 ± 0.5	0.5	9.2	.001
Low crawl	7.3 ± 1.0	9.8 ± 1.9	2.5	34.3	<.001
Seated shot	18.1 ± 3.1	20.7 ± 3.2	2.6	14.7	.004
Rifle drop	11.4 ± 1.4	12.7 ± 1.4	1.3	11.2	.001
Door breach	11.1 ± 1.3	12.9 ± 1.9	1.8	15.8	<.001
Handgun shot	24.5 ± 13.1	21.8 ± 8.1	-2.7	-11.2	.159
Victim rescue	22.0 ± 4.4	25.4 ± 7.4	3.4	15.6	.048
Sprint	9.1 ± 0.8	10.7 ± 1.2	1.6	17.4	<.001

*STT = Simulated tactical test; % change = [(loaded condition – unloaded condition)/unloaded condition] X 100). Values are displayed as mean ± standard deviation.

Comparisons of the resting blood lactate values from before the 1st trial and before the 2nd trial are displayed in Figure 1. Eight of the 12 operators had a greater

resting blood lactate prior to the second trial. There were no differences in RPE, post-test blood lactate, and relative heart rate for the loaded and unloaded conditions ($p > .05$; Table 4). There were also no differences in shooting accuracy, horizontal displacement, and vertical displacement between loaded and unloaded conditions ($p > .05$; Table 4).

Figure 1. Comparison of operators' resting blood lactate values before trial 1 and trial 2 of the simulated tactical test.

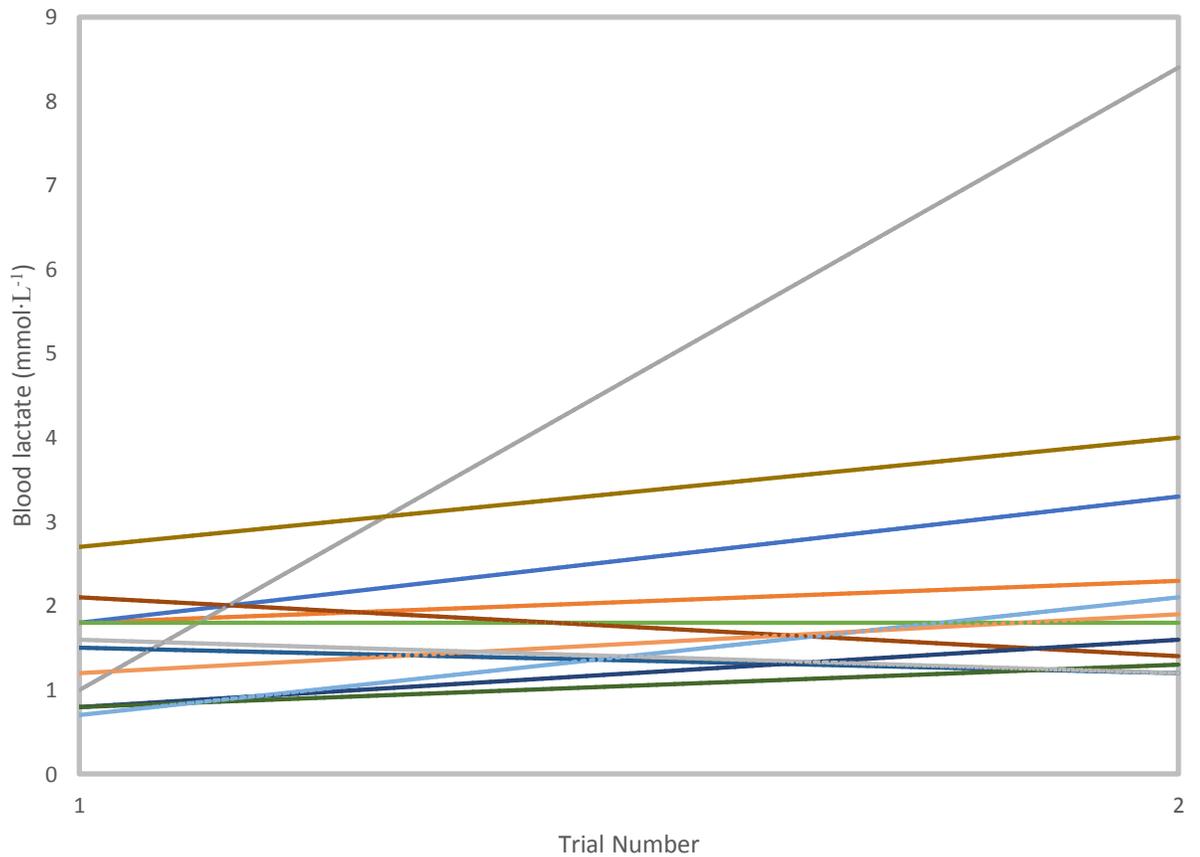


Table 4. Physiological responses and marksmanship on a simulated tactical test in unloaded and loaded conditions in 12 male SWAT operators.

Physiological response	Condition		<i>p</i> -value
	Unloaded	Loaded	
RPE	17.0 ± 1.3	17.2 ± 0.8	.438
Post-test blood lactate (mmol·dL ⁻¹)	12.2 ± 1.3	12.7 ± 1.1	.325
Relative heart rate (%)	89.6 ± 6.1	89.3 ± 6.7	.752
Marksmanship			
Shot accuracy (cm)	5.7 ± 1.7	5.9 ± 2.3	.816
Horizontal displacement (cm)	8.7 ± 2.8	8.9 ± 4.5	.846
Vertical displacement (cm)	9.5 ± 4.9	9.1 ± 4.1	.801

Note: RPE = Rating of perceived exertion; Relative heart rate = [(average heart rate during trial/predicted maximal heart rate) X 100]. Values are displayed as mean ± SD.

A description of the physical fitness outcomes are displayed in Table 5.

Questionnaire data revealed a median value of 4.0 (range: 2 – 6) days per week exercising and a median value of 4.0 for intensity (vigorous; range: 3 – 4). Table 6 represents the correlation matrix between the delta time for each STT task that revealed a significant difference between conditions versus physical fitness outcomes. VO_{2peak} was negatively correlated with the overall STT ($r = -.62$) and door breach delta times ($r = -.67$). Fatigue index was positively correlated with the overall STT and the stair climb delta times ($r = .64, .76$, respectively). Peak relative power was positively correlated with the overall STT ($r = .61$) and seated shot delta times ($r = .58$). Relative vertical jump height was negatively correlated to door breach delta time ($r = -.66$). The number of push-ups was negatively correlated to the stair climb delta time ($r = -.61$). One repetition maximum bench press load was negatively correlated to the agility delta time ($r = -.62$). One repetition maximum leg press load was negatively correlated to the rifle drop delta

time ($r = -.79$). Also, relative leg press load was negatively correlated to the stair climb delta and the rifle drop delta times ($r = -.78, -.74$, respectively).

Table 7 displays the correlation matrix comparing the delta time for each task of the STT versus the SWAT operators' demographic and anthropometric characteristics. There were no significant correlations between the overall STT delta time and any of the demographic or anthropometric characteristics. Body mass, BMI, abdominal circumference, waist circumference, and hip circumference were positively correlated to the door breach delta time (range across tasks: $r = .58$ to $.68$, $p < .05$). Military experience was positively correlated to the sprint delta ($r = .67$, $p < .05$) and exercise frequency was negatively correlated to the stair climb, wall climb, and agility delta times (range across tasks: $r = -.66$ to $-.78$, $p < .05$).

Table 5. Physical fitness outcomes in 12 male SWAT operators.

	Mean	±	SD
Fitness Assessment			
Leg press (kg)	430.5	±	88.2
Relative leg press (kg)	4.6	±	0.8
Bench press (kg)	117.6	±	19.0
Relative bench press (kg)	1.3	±	0.2
Push up (reps)	50.3	±	15.4
Agility (s)	16.9	±	0.9
Vertical jump (cm)	57.4	±	5.6
Relative vertical jump (cm·kg ⁻¹)	0.6	±	0.1
WAnT mean power (W·kg ⁻¹)	7.5	±	0.7
WAnT peak power (W·kg ⁻¹)	10.7	±	0.7
Trunk endurance (s)	152.6	±	39.8
Fatigue index (%)	51.2	±	8.3
Flexibility (cm)	29.6	±	6.8
VO _{2peak} (ml·kg ⁻¹ ·min ⁻¹)	44.8	±	5.3

Note: WAnT: Wingate anaerobic test-mean and peak power outputs; Relative leg press =

leg press 1-RM/body mass; Relative bench press = bench press 1-RM/body mass;

Relative vertical jump = vertical jump/body mass.

Table 6. Matrix representing the correlation coefficients between simulated tactical test (STT) delta times versus physical fitness outcomes in 12 male SWAT operators.

	Relative Leg Press	Leg press	Bench press	Push up	Agility	Relative vertical jump	Trunk endurance	WAnT mean	WAnT peak	Fatigue index	Flexibility	VO _{2peak}
STT Delta	-.264	.001	-.292	-.359	.125	-.274	-.502	-.194	.609*	.639*	.007	-.624*
Stair climb delta	-.780**	-.599	-.394	-.610*	.011	-.350	-.269	-.556	.170	.762**	.039	-.466
Wall climb delta	-.398	-.378	-.512	-.270	-.054	.305	-.484	.222	.278	.197	.239	-.282
Up-and-Go delta	-.270	-.325	-.283	-.134	-.347	.189	-.377	.159	.558	.301	-.040	.055
Agility delta	-.367	-.254	-.620*	-.496	-.354	.059	-.270	.021	.567	.462	-.241	-.305
Low crawl delta	-.466	-.461	-.510	-.228	.185	-.170	.208	-.251	-.137	.139	.174	-.438
Seated shot delta	.238	.119	-.222	-.137	-.353	.191	-.287	.263	.577*	.081	-.168	.087
Rifle drop delta	-.739**	-.794**	-.492	-.109	-.508	.055	.153	-.175	.351	.405	.097	.083
Door breach delta	.080	.533	.086	-.140	.518	-.655*	.181	-.503	-.188	.303	-.451	-.668*
Sprint delta	-.287	-.033	.104	.259	.312	-.389	.343	-.423	-.106	.312	.123	-.363

Note: Only simulated tactical test tasks are included in the table that were significantly different between loaded and unloaded conditions. * $p < 0.05$ level; ** $p < 0.01$; WAnT: Wingate anaerobic test-mean and peak power outputs ($W \cdot kg^{-1}$); Delta time = loaded task time – unloaded task time; Relative Leg Press = Leg Press 1-RM·body mass⁻¹.

Table 7. Matrix representing the correlations between simulated tactical test (STT) delta scores versus demographic and anthropometric variables in 12 male SWAT operators.

	Age	Height	Body mass	BMI	Abdominal	BF %	WC	HC	LEO experience	SWAT experience	Exercise frequency	Exercise intensity
STT Delta	.475	-.060	.198	.228	.388	.399	.338	.150	.555	.500	-.355	-.023
Stair climb delta	.164	-.026	.196	.204	.393	.465	.333	.274	.503	.567	-.777**	-.421
Wall climb delta	.114	.035	-.241	-.230	-.027	-.096	-.059	-.119	.181	.118	-.659*	-.197
Up-and-Go delta	.093	.296	-.156	-.303	-.019	-.068	-.041	-.099	.316	.024	-.249	.093
Agility delta	.162	-.017	-.016	.004	.161	.141	.240	.185	.186	.219	-.700*	-.240
Crawl delta	.044	-.296	-.128	.029	-.028	.168	-.021	.142	-.063	.000	-.436	-.047
Seated shot delta	.413	-.375	-.211	-.025	-.133	.101	-.035	-.161	.154	.195	.054	-.072
Rifle drop delta	-.338	.388	-.242	-.426	-.149	-.269	-.200	-.178	-.165	-.202	-.533	-.377
Door breach delta	.174	.048	.682*	.651*	.635*	.486	.603*	.580*	.300	.270	.015	.338
Sprint delta	-.057	.234	.258	.159	.197	.067	.112	.043	-.008	.055	.003	-.059

Note: Only simulated tactical test tasks are included in the table that were significantly different between loaded and unloaded

conditions. * $p < 0.05$; ** $p < 0.01$; Delta times = loaded task time – unloaded task time. BF: Relative body fat; BMI: Body mass index;

WC: waist circumference; HC: Hip circumference; LEO: law enforcement officer experience (yr); SWAT: special weapons and tactics experience (yr).

Chapter V: Discussion

The primary purpose of this study was to determine the effect of load carriage on the simulated tactical performance of SWAT operators. As hypothesized, the addition of gear was found to negatively affect the task efficiency of the SWAT operators while performing the STT. The 7.8% increase in time was likely due to the increase in workload and decrease in mobility with the addition of gear. The findings from this study further emphasize the fact that although load carriage is necessary for operational success and safety, the negative impact on performance must be considered. As evidenced by the positive delta times, 69% of the physical STT tasks took longer to complete when the operators were in a loaded condition. Interestingly, most of the tasks that exhibited no difference between conditions were shooting tasks that did not require much physical movement.

Research on the effect of occupational load carriage on task efficiency is not novel among other tactical populations. For instance, Carlton et al. (14) observed a significant effect of load carriage on the efficiency and marksmanship of specialist police officers. Specifically, officers carrying a load greater than 25% of body mass required greater time to complete a tactical task compared to an unloaded condition. The officers' efficiency was not affected when carrying a load less than 25% of body mass. These findings do not support those of the current study in which a relative load of $15.5 \pm 2.5\%$ produced a significant increase in time to complete the tactical course. Although a lighter load was utilized in the present study, our tactical course was longer which required carrying the load over a greater distance (present study: 265 m vs. Carlton et al. (14): 25 m). This duration may have allowed compounding fatigue to affect physical performance on each subsequent task and on the course in its entirety. Also, the small

sample size utilized by Carlton et al. (14) may have attributed to the lack of significance with the lower relative load ($N = 6$).

The influence of load carriage has been evaluated on short sprinting maneuvers as well (42,55). Treloar et al. (55) found a 31.5% increase in the average time to complete five maximal 30 m explosive, prone to sprinting trials while wearing combat body armor compared to not wearing armor ($p < .05$). The five sprints occurred at a rate of one every 44 seconds, resulting in a rest time of approximately 35 seconds. Furthermore, there was a significant order effect across sprint trials in the loaded condition, indicating that there was a greater effect of load carriage on the later trials. This movement is most similar to our stand and sprint (i.e., up-and-go task) task performed immediately after the prone shot, where we observed it took operators 13.5% longer to complete the task in the loaded condition. The greater decrement in performance reported by Treloar et al. (55) could be explained by the greater load carried (Treloar et al.: 21.6 kg vs. present study: 14.2 kg), the fact that none of the soldiers in their study had experience wearing combat body armor, or because the up-and-go task in the present study was performed in sequence with other physical tasks, without recovery and thus may not have represented a maximal explosive effort.

Lewinski and colleagues (42) also reported a significant effect of wearing a 9.07 kg ($11.47 \pm 1.64\%$ body mass) weighted belt on sprint performance. The sprints were performed from 4 starting positions: forwards, backwards, 90 degrees left and 90 degrees right. One minute recovery periods were allowed between trials. The primary finding was that excess weight carried by operators resulted in 5% decrease in sprint stride velocity. The researchers attributed their results to an increase in ground contact time that likely increased eccentric loading which, in turn, overloaded the muscles during the stretch-shortening cycle. Similar movements

demanding explosive acceleration and change of direction in the STT were the up-and-go, the agility, and the sprint. These movements did exhibit a greater decrement in performance in the current study (13.5%, 9.2%, 17.4%). This result is most likely due to the greater load carried or by the compounding fatigue associated with completing the tasks in succession without rest.

Dempsey et al. (20) also investigated the effect that stab resistant body armor and associated equipment had on the physiological responses and performance of New Zealand police officers during simulated mobility tasks (balance task, grappling task, acceleration from a seated position, chin-ups, & push-up position maneuverability task). The load consisted of body armor and a weighted belt (7.65 ± 0.73 kg). All of the tasks were negatively impacted by wearing the body armor with performance decrements from 13-42% ($p < 0.001$; 20). Also, in an attempt to replicate a near maximal running effort in a worst case scenario each operator completed a 5-min run at $217 \text{ m}\cdot\text{min}^{-1}$. Following the run (and 1 minute rest) all mobility tasks were repeated. Only in the loaded condition was performance in all mobility tasks further reduced (6-16%; $p < .001$). No significant difference was observed in mobility task performance between the unloaded mobility task performance before and after run.

Previous research has also investigated the effect of increasing load carriage mass on the completion times of maximal effort tasks. Similar to our study, Hasselquist and colleagues (32) observed an increase in completion times of an obstacle course when Army soldiers wore torso, torso with upper extremity, and torso with full upper and lower extremity armor coverage (14.8 kg, 18.45 kg, and 20.40 kg, respectively). The addition of upper extremity and full body armor resulted in a decreased performance of 15.8% and 23% respectively, compared to no armor. The findings also revealed a 9% increase in VO_2 during treadmill running at $140.4 \text{ m}\cdot\text{min}^{-1}$ while wearing extremity armor compared to no armor (32). The obstacle course tasks used were

similar to the present study, involving stairclimbing, agility movements, sprinting, and crawling movements.

Fitness and Load Carriage

To the best of our knowledge, this was the first study to investigate the relationship between physical fitness variables and the change in performance with the addition of gear. Current literature has investigated aspects of fitness and the relationship with performance in a loaded condition. However, there is little information about the relationship between fitness variables and the decrement in performance due to the addition of gear. This information is important because performance of these tasks are critical for operator safety and survival, as well as mission success. Thus, it is crucial to identify and enhance fitness characteristics that prepare operators for the physiological demands of load carriage.

When considering all of the tasks within the STT, 9 tasks required more time to complete while in the loaded condition ($p \leq .01$). In general, these tasks were more physically demanding and required dynamic movement patterns. Specifically, lower body explosiveness was required for the stair and wall climb tasks as well as the up-and-go task. The agility task required explosive acceleration, deceleration, and change in direction. The low crawl task required upper body muscular endurance, however the increase in completion time observed was most likely due to the gear limiting the mobility of the operator within the confinement of the crawl space. This task was most sensitive to the addition of gear, as evidenced by the 34.3% increase in time to complete this movement, suggesting that the restrictive nature of gear may be more impactful than the mass itself. The door breach was a task that involved lower body strength, trunk endurance, as well as aerobic energy systems. The rifle drop and sprint were both anaerobic

sprinting maneuvers covering 33 m and 35 m, respectively. The increase in time observed for these movements is similar to that of Holewijn et al. (34) in which the addition of a 16 kg load resulted in a 13% increase in 80-m sprint time. If performed independently, each task within the STT is anaerobic in nature and involved varying degrees of muscular power and endurance. However, because the STT tasks were performed consecutively and without recovery, the STT also included an element of aerobic endurance.

Of the 13 tasks in the STT, 4 tasks did not result in a significant difference in time between the unloaded and loaded condition (barrel shot, standing/prone shot, handgun shots, and victim rescue). Three of the 4 tasks were shooting related and required very little ambulation or physical exertion to complete the task. However, one of the shooting tasks, the seated shot, took longer to complete in the loaded condition. This may have occurred because of the longer distance (17 m) that was required to maneuver to this shooting location from the start of the task. The victim rescue task was not significantly different between the two conditions but was trending toward taking longer while in the loaded condition ($p = .048$, Table 3). A decrease in speed of the dummy drag movement has been observed in the loaded condition in other investigations (14,15).

Peak VO_2 was negatively correlated with the overall STT delta and door breach task delta times. Peak VO_2 is a measure of cardiorespiratory fitness. The negative correlation suggests that as cardiorespiratory fitness increases, the negative impact of load carriage diminishes for the overall course and for the door breach task. It seems logical that the influence of gear on the overall STT course performance would have a relationship with cardiorespiratory fitness. Although many of the individual tasks that compose the STT are anaerobic in nature (wall hurdle, short sprints), however, when performed in its entirety the course requires oxidative

energy production (mean STT time > 3.4 min). The door breach task was also negatively correlated to VO_{2peak} . Although the act of breaching a door by itself is an explosive movement requiring anaerobic energy production, the task also included running 30.8 m, while carrying a 19.1 kg battering ram. It is likely that the arduousness of this task, combined with the placement of this task later in the STT produced an inverse relationship with aerobic capacity. That is, lesser aerobically trained operators slowed down more during this task than more aerobically fit operators. Relative vertical jump height was also negatively correlated with the door breach task delta time. The vertical jump is a test of peak power. Phosphagen energy utilization as well as rate of force development for the lower body musculature are the major components of this fitness test. The negative correlation would suggest that as the rate of force development increases, the sensitivity to load carriage during the door breach task decreases.

Research has indicated that load carriage can also have an effect on respiratory muscle fatigue. Body armor has been observed to cause chest wall restriction and result in a decrease in exercise tolerance and increased fatigue (17). This in turn reduces overall operator performance and increases perceived exertion. Possible thoracic restriction may have produced a decrease in performance, independent of the mass carried (17,22,55).

Fatigue index measured during the WAnT was positively correlated with the overall STT delta and stair climb delta times. A higher fatigue index represents a greater decrement in power output due to increasing neuromuscular fatigue (4). The positive correlation suggests that as fatigue increases, so does the individual's sensitivity to load carriage for the overall course and specifically while ascending and descending stairs.

Relative peak power was positively correlated with the overall STT delta time and the seated shot task delta time. Relative peak power is defined as the highest power output produced during the 30 second WanT. The positive correlation suggests that as peak power increases for an individual, so does the sensitivity to load carriage for the overall course (i.e., glycolytic & oxidative demands) and for the seated shot task. The STT course contained many tasks involving phosphagen and glycolytic energy utilization (wall hurdle, prone to sprint, sprint, stair ascent/descent). Since the peak power is primarily a measure of the phosphagen energy system it would be logical to expect an individual with higher peak power to be less affected by added resistance. Differences in skeletal muscle fiber type may explain this phenomenon. It is possible that the individuals with greatest peak power have a muscle architecture more rich in type IIB fibers. Type IIB fibers produce the greatest amount of force and are fastest contracting, but they are quick to fatigue and have little oxidative capabilities (27). When resistance exercise is performed regularly the net result is that these IIB fibers are converted to type IIA. Type IIA have a greater oxidative enzyme capacity, mitochondrial density, and resistance to fatigue. Considering this distinction in fiber type characteristics it is important to consider the effect of load carriage on tasks performed independently with ample rest between sequential tasks.

The number of push-ups performed was negatively correlated with the stair climb task delta time. The push-up test is a measure of upper body muscular endurance. This negative correlation would suggest that as upper body muscular endurance increases, the sensitivity to load carriage during the stair ascent/descent movement decreases. There is little rationale for upper body muscular endurance to play a role in a stair climb movement given the independence of muscular adaptations (12). However, we did not assess lower body muscular endurance in this study which would have evaluated this relationship more accurately. It is possible this

finding was simply a result of general training status. That is, it is possible that operators who possess greater upper body muscle endurance may also possess greater lower body muscle endurance due to the nature of their training program. This relationship has been reported in other tactical investigations as well. For instance, Beck et al. (5) reported that number of push-ups performed by campus police officers was inversely related to stair ascent/descent and 159 m sprint completion time. Previous literature has also observed a correlation between upper body resistance training and an increase in load bearing task performance (39,40). This is possibly due to the increased ability to stabilize the torso and retain proper posture while decreasing energy expenditure.

The 1-RM bench press load was negatively correlated to the agility task delta time. The 1-RM bench press test is a measure of upper body strength. The negative correlation would suggest that as upper body strength increases, the sensitivity to load carriage decreases for an agility movement. For this relationship as well there seems little rationale other than as a general indicator of overall fitness.

The 1-RM leg press load was negatively correlated with the rifle drop task delta time. The 1-RM leg press is a measure of lower body strength. The negative correlation suggests that as absolute lower body strength increases, the sensitivity to load carriage decreases for a movement similar to the rifle drop task. When body mass was taken into account, relative leg press load was negatively correlated with rifle drop delta and stair climb delta times. Relative strength-to-mass ratio directly reflects an operator's ability to move or accelerate his or her own body. The negative correlation suggests that as relative strength increases, the sensitivity to load carriage decreases for movements similar to the rifle drop task and the stair climb. These tasks

did involve a lower body power/strength component as the operator sprinted up and down steps and lifted himself from the seated shot position and sprinted 33 m to the rifle drop location.

Exercise frequency was negatively correlated to the stair climb, wall climb, and the agility task delta times. This suggests that as exercise frequency increases, sensitivity to load carriage decreases for these three tasks. This should be an encouraging result for the tactical strength and conditioning professional. This relationship is evidence that increased exercise activity can help to diminish the negative impact of load carriage.

Body mass, BMI, abdominal circumference, waist circumference, and hip circumference were positively correlated to the door breach task delta time. The positive correlations suggest that as girth is increased, the sensitivity to load carriage is also increased for the door breach task. A positive relationship would be expected between fat mass and performance decrements due to increased loads. The increase in adiposity is an additional physiological burden that could exacerbate the effect of the load and reduce the operator's work efficiency.

There were no significant differences between unloaded and loaded marksmanship variables (average distance from center of target, horizontal displacement, or vertical displacement). These results suggest that although task efficiency is decreased with the addition of SWAT specific gear, marksmanship remains unaffected. Carlton and colleagues (14) also observed no significant difference between the marksmanship of unloaded and loaded conditions with a Tactical Operations Unit. The participants in the study were instructed to complete a 25 m tactical course consisting of a 10 m sprint and stair descent, followed by 5 shots on a target using a secondary weapon (9 mm Glock pistol).

Considering that carrying gear increases energy expenditure and cardiorespiratory demand, it is logical to assume a decrease in marksmanship would occur when a load is added to the operator (20,50). However, our results suggest otherwise. Results have shown that tactical load may not reduce, but may actually improve certain aspects of marksmanship. Consideration has been given to the fact that body armor can add a stabilizing effect to the torso, in particular the shoulder girdle (13,14). This could possibly offset the potentially confounding physiological responses. Also, anecdotal remarks from tactical operators suggest that increased experience with a specific weapon while wearing tactical gear may help to overcome the physiological responses and enhance marksmanship. Thus, it appears that technical skill acquisition and experience with weapons and tactical gear play a critical role in marksmanship.

Limitations

There are several limitations to this study. First, this study utilized a relatively small sample size. However, significant correlations were identified, indicating adequate statistical power for some relationships. In addition, we choose to not allow recovery between STT tasks. Future research should consider evaluating the relationship between physical fitness outcomes and load induced performance decrements while allowing full recovery between tactical tasks. It is possible that this approach may indicate that greater absolute power outputs are associated with less sensitivity to load carriage on power-based tasks. This testing strategy would decrease the glycolytic and oxidative demands of performing multiple tactical tasks without recovery. However, real world scenarios involve performing both a single brief explosive task and performing multiple tasks in succession. It is important to understand the effect that load carriage and physical fitness have on performance in each situation.

For the assessment of cardiorespiratory fitness a prediction equation was utilized instead of a criterion measure. The equation was developed in a tactical population (53).

Despite a non-significant difference indicated by a paired sample T-Test, there was a trend toward a difference in resting blood lactate values ($p = .112$; Trial 1 resting blood lactate: $1.48 \pm .61 \text{ mmol}\cdot\text{L}^{-1}$; Trial 2 resting blood lactate: $2.54 \pm 2.04 \text{ mmol}\cdot\text{L}^{-1}$; Figure 1). The median recovery time for each operator between each trial was 3.18 hours and the range was 2.72 – 3.40 hours. This duration has been shown to be adequate to negate any residual blood lactate accumulation from the 1st trial (9,26). A potential reason for an increased pretrial lactate in certain operators could be due to their participation in resetting the STT course during their recovery period.

Given that one familiarization trial was performed and both official loaded and unloaded STT trials were performed on the same day it is reasonable to question (a) whether one familiarization trial was adequate to obtain a reliable performance on the official STT trials and (b) if performing both official trials on the same day produced fatigue that impacted the second trial. In order to rule out any confounding effect of trial order or familiarization, (loaded condition first or unloaded condition first) further analysis was conducted. First, a randomized counterbalanced design was used to ensure some participants performed the loaded condition first, while others performed the unloaded condition first. Second, the test-retest reliability of the STT when comparing the 12 operators' familiarization trial (performed in loaded condition) and the official trial in the loaded condition was $\text{ICC} = .913$ ($n = 9$). Furthermore, there was no difference between the STT times of the operators that performed the loaded trial first and their familiarization trial in gear (Familiarization trial: $237.7 \pm 41.0 \text{ s}$; Loaded trial: $218.6 \pm 26.8 \text{ s}$; $p = .240$). Similarly, there was no difference between the STT times of the operators that performed

the loaded trial second and their familiarization trial in gear (Familiarization trial: 188.6 ± 9.6 s; Loaded trial = 191.0 ± 11.7 s; $p = .770$). In conclusion, these data indicate that performing the unloaded trial first did not cause undo fatigue that affected the second trial on the same day, instead it indicates that wearing the gear during the second trial produced the slower STT time. Furthermore, these data provide justification that there was no familiarization effect that caused a difference in completion times between the individuals that performed the loaded condition first and the individuals that performed the loaded condition second.

Practical Applications

The results from this study can be used by training officers and tactical strength and conditioning professionals to guide exercise program design for SWAT operators. Previous literature among military populations suggests that concurrent resistance and aerobic training combined with a progressive load carriage stimulus is most beneficial to prepare for load bearing tasks (30,40). Our research indicates that aerobic capacity and anaerobic fatigue are important fitness characteristics for reducing the negative effect of load carriage on task efficiency when performing multiple tasks in succession. These results suggest that the training stimuli should consist of intensities that stimulate oxidative and glycolytic energy systems. Examples of training may include low-to-high intensity endurance exercise, circuit training, and high-intensity interval training (HIIT) variations. It is also important to include training for power development as many of the tasks require explosive movements. Our results also highlight the importance of sufficient exercise frequency within a training program. The appropriate training frequency will depend on each operator's physical training status. Additionally, the principle of specificity must be considered when training an individual for load carriage. A recent review of the current literature regarding load carriage physical conditioning within military populations stated that

two to four load carriage sessions should occur per month, carrying loads that are initially light yet progress in weight to meet operational load requirements. Periods of recovery throughout the program are important to allow body recovery. Care should be taken to increase the loads conservatively to mitigate an increased risk of injury. Training variables, intensity of tasks performed under load and duration carried should be increased gradually, however not at the same time as the increase in load. Strength and aerobic training that incorporate occupationally-specific movement patterns should be utilized (37,46).

Chapter VI: Summary

The primary purpose of this study was to investigate the effect of SWAT load carriage on operator task efficiency and marksmanship. The secondary purpose was to investigate the relationship between physical fitness characteristics and changes in tactical performance. The findings indicate that tactical gear does reduce SWAT operators' tactical efficiency, but not marksmanship. Furthermore, this study found that aerobic capacity and anaerobic fatigue were associated with decrements in work capacity due to load carriage.

Conclusions

In summary, SWAT operators are expected to participate in physically demanding and dangerous tasks when critical situations arise. The gear worn by the operator exacerbates the workload and negatively affects their physical ability. In order to mitigate the negative effects of load carriage, specific physical conditioning must take place. The key exercises within a SWAT specific load carriage training program should utilize strategies that enhance the glycolytic and oxidative energy systems.

Future Directions

Further research is needed to elucidate specific training strategies which improves SWAT operational performance. Future research should also investigate the impact of load carriage on task efficiency while performing individual tactical tasks. Isolating each task will allow the researcher to observe the effect of load carriage on the performance of each task without the influence of fatigue induced by previous tasks. It would also be advantageous to identify potential biomechanical limitations imposed by load carriage as well, in particular the effect of the configuration of SWAT load carriage on tactical movements.

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