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A Quantification Of The Metabolic Demand Wrought By Explosive Ordinance Disposal Load Carriage

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Abstract

In the last 7 years, there have been landmark studies concerning Explosive Ordinance Disposal (EOD) load carriage. These studies (Bach et al., 2017; Wu et al., 2022) have worked to quantify the ability of an operator to work while encumbered by EOD personal protective equipment (PPE), but have not evaluated possible sources of mitigation for the increased demand. Intuitively, it seems that greater levels of fitness would modify the degree of increased demand an operator may acquire during EOD load carriage. The current study seeks to illuminate relationships between strength, power, and/or endurance and EOD load carriage performance. Recreationally trained subjects will complete weekly testing visits over the course of four weeks. For the present study, data capture included a familiarization visit (FAM) wherein the subjects performed the testing protocol without additional load and a loaded visit (EOD) where the subjects wore EOD gear. The visits will had nearly identical testing protocol, where subjects in the larger study performed a battery of tests which included resting heart rate (HR) and blood pressure (BP), body composition, reaction time, hand grip strength, vertical jump, isometric rack pull, stair sprint, 18.29m sled pull, 9.14m yard dash, a Bruce or modified Bruce protocol, and digit countback. The present study specifically considered measures of strength (isometric rack pull), power (stair sprint, sled pull), and cardiovascular fitness (VO2 max) to give insight to the relationship between strength, power, and cardiovascular fitness and aerobic capacity under load. Findings include an increase in HR, VO2, and RER through all stages and an increase in RER through the second and third stage. Strong correlations were found between Relative strength, body fat percentage, VO2 max, and FAM Bruce duration and EOD Bruce duration.

Keywords: Load carriage, tactical athlete, EOD equipment, PPE, Bruce protocol.

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I. Introduction

Load carriage is the ability to move and perform work while carrying an additional load, such as protective equipment or supplies. This ability is crucial to the performance of tactical athletes, in terms of safety, speed of ingress/egress, and the mitigation of the stresses of fieldwork. The loads these athletes carry are often storage, tools, or personal protective equipment (PPE). The body of research concerning the physiological effects of load carriage has been growing over the last 15 years, but most of this research has been conducted utilizing infantry loads and/or rucksacks. Explosive ordinance disposal (EOD) gear is a heavier and more encumbering form of personal protective equipment, and its effects on performance are largely unquantified/unstudied. The present study specifically explores the correlation between individual factors including strength, power, and endurance and the degree of increased metabolic demand that EOD load carriage requires. This experiment is part of a larger study that seeks to quantify the effects of load carriage on physiological factors and cognitive performance variables such as body composition, power, strength, aerobic capacity, reaction time, and short-term memory during activities in four different load configurations; unloaded, firefighting PPE, law enforcement PPE, and EOD PPE.

Research Problem

The current body of literature pertaining to load carriage details the effects of personal protective equipment, supplies, and tools on biomechanics, metabolism, and orthopedic injury (Bastien et al., 2005; Blacker et al., 2003; Godhe et al., 2020; Martin, Nelson, 1986). However, relatively little research exists that considers the extra impedance that explosive ordinance disposal personnel encounter in the field. Since EOD personnel carry heavy gear that most likely reduces mobility and the ability to regulate thermic stress, we can hypothesize that demands in terms of both strength and aerobic capacity will differ from previously established literature. It is important to fill this gap in the literature because extrapolating findings from infantry load carriage to EOD personnel is academically irresponsible, and could lead to less effective programming for these tactical athletes. The present study would further illuminate several areas that the above-mentioned EOD load carriage articles have not touched upon:

- Cardiac Drift: The tendency for heart rate to increase while stroke volume decreases, despite the maintenance of exercise intensity. A leading factor in the onset of cardiac drift is core body temperature, which is likely increased by EOD PPE.
- Power: Power is the ability to perform mechanical work quickly, and operators are likely to encounter scenarios in which they require powerful movements. No present study has studied the maximal power output or the probable decrement in power output caused by EOD PPE. Further, this study may illuminate relationships between power and a decrease in the increased metabolic demand encountered while carrying EOD PPE.
- Strength: Strength is the ability to perform mechanical work regardless of time. No present study has studied the maximal strength of their subjects in tandem with maximal strength after carrying EOD PPE. More importantly, higher measures of

strength may be correlated to the softening of the increased metabolic demand, but this correlation has not been studied.

- Cardiovascular Fitness: Likewise, no present study has included an examination of cardiovascular fitness to the degree that the present study sought to do. Where indirect calorimetry has been utilized, heart rate has not, nor maximal unloaded VO2. These variables are integral to assessing cardiovascular work and an individual's ability to perform work over time. Lastly, subjects with greater cardiovascular fitness may be able to have an increased ability to stave off some of the increased metabolic demand.

The research will seek to answer two primary questions:

To what degree does EOD gear increase metabolic demand during an incline walk?

Is there a correlation between strength, power, or cardiovascular fitness to the change in this increased demand?

EOD personnel deal with high pressure, high stakes situations that deeply affect the lives of the operator and the lives of those around them. Thus, members of the exercise and sports science field should focus their efforts to provide a stronger foundation for future studies into load carriage.

Working assumptions

This research was conducted with a set of working assumptions. The first is that trained EOD personnel do not respond to wearing EOD gear in such a radically different way to recreationally trained subjects that the results of the study will be inapplicable. This seems unlikely, because while a learning effect may reduce the impact of load carriage on metabolic demand, surely similar relationships are shared between purpose-trained and recreationally trained athletes. Another was the assumption that subjects have routines that replicate on a weekly basis.

Limitations

The replication of weekly schedules is a working assumption that worked as a solution to a potential limiter; the limiter being control over extraneous variables related to subject performance, such as diet, sleep, and fatigue from their own exercise habits. These factors all play a role in performance, but are outside of the control of the researcher. By planning visits the same time each week, these extraneous variables were more controlled/consistent (Kusumoto et al., 2021). Another limitation may have been access to the space necessary to perform the sled drag, though this only affected one subject. A third limitation was access to able-bodied participants that are willing to sacrifice enough time to make the testing possible, given the time-consuming and labor-intensive nature of the protocol, as subjects took 45-60 minutes per visit.

Delimitations

This study included several delimitations to control for extraneous factors pervading research. To control for the effects of the subject's varied weekly schedules (concerning nutrition, sleep, training regimen), the visits were scheduled for the same time and day once a week. This study utilized a crossover design, so that the subjects served as their own control, to avoid complications from having to control with an unloaded group vs a loaded group. The order of visits was randomized as a part of a larger study that also utilized fire and police PPE in order to mitigate possible benefits from a learning effect, wherein subjects become better at tasks through repetition.

Research Questions

1. To what degree does EOD load carriage effect metabolic demand in terms of HR, VO2, RER, and RPE during an incline treadmill walk?
2. Is there a relationship between strength, power, and the change in metabolic demand?

Null Hypothesis

1. EOD load carriage will not increase metabolic demand in terms of HR, VO2, RER, and RPE.
2. Subjects with greater baseline strength and power do not experience any change in the increased in metabolic demand.

Alternative Hypothesis

1. EOD load carriage increases metabolic demand in terms of HR, VO2, RER, and RPE.
2. Subjects with greater baseline strength and power experience some change in the metabolic demand increase brought on by EOD load carriage.

Significance

This research serves to begin to fill a gap in the literature pertaining to EOD load carriage. Through its exploratory nature and broad probing of many variables, this study should be able to illuminate areas for future research and quantify some differences in metabolic demand concerning the carriage of EOD gear, and provide a degree of guidance towards which kinds of fitness are more advantageous for EOD load carriage.

Summary

Existing literature pertaining to load carriage has been written based on research utilizing mostly infantry loads, with a few studies devoted to police and firefighting protective equipment, and a few recent additions for EOD carriage. This presents a gap in our understanding of how EOD load carriage effects performance, especially in terms of power output. The present study sought to illuminate EOD load carriage's effects on metabolic demand, muscular power and strength, and to what degree the strength, power, and endurance of the individual can affect the increased metabolic demand associated with load carriage. This study could establish means to extrapolate existing findings pertaining to infantry, firefighting, and police load carriage onto EOD load carriage, and/or make the case that significantly more EOD load carriage needs to be researched.

Terms

- Tactical Athlete- Refers to members of fire and rescue teams, law enforcement, military personnel, or any other “active duty” professions, in which personnel are required to upkeep some level of physical fitness in order to meet their professional demands.
- Load Carriage- The act of carrying heavy loads over time, typically in the form of personal protective equipment.
- Personal Protective equipment (PPE) - clothing and equipment that is worn or used to provide protection against hazardous substances or environments.
- Explosive Ordinance Disposal (EOD)- the detection, identification, on-site evaluation, rendering safe, exploitation, recovery, and final disposal of explosive ordnance, usually pertaining to law enforcement or military personnel.
- Work – The ability to displace an object via the application of force.
- Power – The ability to perform work in a short amount of time. To displace a heavy object quickly exhibits a high amount of power.
- Strength- The ability to perform maximal work regardless of time. To be able to apply high amounts of force, no matter how long it takes, exhibits a high amount of strength.
- Endurance- The ability to perform work over an extended period of time. To exert force for an extended duration, regardless of the amount of force applied, exhibits a high amount of endurance.

- Rate of Perceived Exertion (RPE) - A rating (from 1-10 for this study) given by the subject to express their subjective level of strain due to the testing protocol.
- Respiratory Exchange Rate (RER) - The ratio of carbon dioxide produced by the body over the oxygen consumed, as represented by a decimal.

II. Research

Research Question

Current findings concerning the relationship between measures of strength, power, and endurance that pervade infantry load carriage research may or may not be applicable to the load carriage efforts of explosive ordinance disposal personnel. Research needs to be conducted to quantify the demands encountered by the more niche population of EOD specialists, and to further understand the relationships between strength, power, and endurance when it comes to load carriage performance. This study seeks to quantify the correlations between power, strength, and endurance and the change in the increased metabolic demand brought on by EOD load carriage.

Background

Tactical athletes usually belong to rescue, military, or law enforcement professions. These individuals differ from our conventional idea of athletes in that their task-specificity in terms of physiology is lower, they cannot plan their training around specific competitive periods, and the events or “competitions” that their training is programmed to prepare them for are almost exclusively high pressure, potentially lethal, destructive, and full of chaos. Therefore, tactical athletes cannot periodize as effectively towards a peak, they cannot taper, and they must remain fit for duty during the length of their service (this means these athletes are essentially perpetually in-season). Firefighters, explosive ordinance disposal (EOD) units, law enforcement, and military personnel have all seen great degrees of technological advancements concerning the equipment they must perform in/with. These advancements include heavier yet more effective weaponry, PPE, and tools (Knapick et al., 2004). With these advancements, the effort required to carry this equipment has increased, and this is likely especially true for EOD personnel.

Explosive ordinance disposal personnel wear protective gear that include chaps, integrated groin protection, helmet, vest, optionally a self-contained breathing apparatus (SCBA), and demining boots. Combined, this equipment has a weight of approximately 35 kilograms, in addition to any tools carried. (Stewart et al., 2011). Intuitively, we can hypothesize that this gear has a non-zero effect on body heat, metabolic demand, and cognitive function, all of which are required for safe and effective operation in the field. Current literature, though focused on infantry personnel and the loads specific to them, supports this hypothesis, as will be discussed in the following literature review.

As previously stated, a majority of existing literature has been documented on the load carried by infantry personnel (Drain et al., 2016; Knapick et al., 2004; Seay et al., 2015). The loads of these personnel usually includes, but is not limited to, body armor, combat uniform, rucksack, helmet, and infantry rifle (Knapik et al., 1996). The data obtained by these load carriage experiments has been shown to be similar to that obtained by EOD gear, but the effect on metabolic rate seems to be disproportionately larger for the EOD personnel (Bach et al., 2017; Wu et al., 2022). Thus, the literature discussed in this review will be focused around infantry load carriage, but we should keep the relationship between the infantry load and the EOD load in mind.

Common Methodologies

In studying what makes an individual proficient at load carriage, it is common for researchers to employ the same techniques commonly found in exercise science research. To assess strength, they often use one repetition maximum (1 RM) bench pressing, back squatting, and deadlifting (Morrissey et al., 1995; Szivak et al., 2015). To assess aerobic capacity and endurance, researchers use shuttle run tests, VO2 max protocols, and time trials (Grant et al., 1999). Vertical jump and sprint tests have commonly been used to assess power (Harman et al., 1991; Sleivert & Taingahue, 2004). A necessary, appropriate, and somewhat novel addition to these standard and familiar measurements are the loaded walks or marches, which usually take place on a treadmill with and without additional load, designed to simulate load carriage in the field (Godhe et al., 2020; Szivak et al., 2015). To this end, a majority of the literature reviewed utilized load carriage designed to mimic the tactical athlete's field load and environment as closely as possible. Research pertaining to law enforcement utilized tactical vests, research pertaining to fire fighters utilized firefighting gear, and, most prevalently, research pertaining to infantry personnel utilized rucksacks and military body armor (Dempsey et al., 2013; Godhe et al., 2020; Martin & Nelson, 1986).

In terms of experimental design, most subjects served as their own controls through a variety of configurations, and correlation is examined between different variables during each loaded trail and the unloaded trial. Statistically, T-tests and ANOVA are commonly utilized, along with regression models, power tests, and the standard measurements of means, maximums, and standard deviations (Bastien et al., 2005; Blacker et al., 2003; Boffey et al., 2019; Keren et al., 1980; Godhe et al., 2020; Robinson et al., 2018; Spudić et al., 2021).

Population samples usually included males, sometimes with females, between the ages of 20 and 45, typically at least recreationally trained (Godhe et al., 2020; Mala et al., 2015). Many studies have also utilized Reserve Officer's Training Corps (ROTC) groups or other groups that have load carriage experience (Krajewski et al., 2014; Sol et al., 2018). This is an important point of note because as will be discussed later, there is a learning effect positively associated with load carriage. It is also worth noting that most studies attempt to use subjects that reflect the intended population, as is standard in most experimental research.

Synopsis of Present Knowledge

Research has suggested a strong relationship between aerobic fitness and the ability to carry loads over distance. As recently as 2020, a strong correlation was found between body mass, body height, leg muscle strength, and absolute VO_2 max in carrying loads of 35 and 50 kilograms in experienced and inexperienced men and women (Godhe et al., 2020). These findings were not replicated in the trials completed utilizing the 20 kg load, where the only correlated variable to performance was body composition. The data given by the lighter intervention do not weaken the premise that aerobic fitness is necessary for EOD load carriage performance, as no presently effective EOD gear is as light as 20 kg. The findings with the 35 and 50 kg intervention also indicate leg muscle strength (as measured in watts by explosive squats in a smith machine with 20, 35, and 50 kg, along with an additional squat loaded with body weight) as a correlate of load carriage performance. This is consistent with findings by an alternative study, which indicate that tactical athletes require a combination of strength, power, and endurance in order to be effective in the field (Mala et al., 2015). This requisite for well-rounded physical capability within tactical athletes is in conflict with many standing principles concerning training specificity. Two other studies have found that concurrent cross-training for strength and endurance does not promote improvement as quickly as specific training does per the specifically targeted training pathway (Foster et al., 2015; Morrissey et al., 1995).

A study has also established the need for aerobic fitness above the need for strength for load carriage (Robinson et al., 2018). The study found that when carrying a 25 kg rucksack, aerobic fitness as measured by beep style tests had the strongest correlation with all tested load carriage events. Lastly, and most pertinently, as recently as 2022, consistent physiological effects were observed in subjects when tasks were performed in EOD PPE. Compared with the same tasks without EOD PPE, subjects consumed more oxygen and at a higher rate. Further, after correcting for the EOD PPE weight, the researchers did not observe any significant difference between the two conditions. Compared with the no EOD condition, the average and maximal HR, respiration rate (RR), and temperature of all participants during the mobility tasks were higher in the EOD condition (Wu et al.,2022). These mobility tasks were performed in sequence through an obstacle course while wearing a portable expired gas analysis device. This study is likely the most comprehensive available EOD load carriage study available to date. The first attempt to quantify the increase in metabolic demand brought on by EOD load carriage yielded findings including metabolic demand increases at walking speeds of 2.5, 4.0 and 5.5 km/h in EOD than without by 49%, 65% and 78%, respectively (Bach et al., 2017). This study found considerably higher increases in metabolic rate than those reported in previous studies utilizing different forms of PPE. Table 1 portrays some of the various loads, interventions, and progressions utilized in some of the reviewed literature.

Table 1: Loads, Interventions, Studied variables, and Findings of Previous Studies

Study	Load	Intervention	Variables studied	Relative increase
Wu et al., 2022	Unloaded, EOD PPE	Obstacle Course	VO2 Temp (C) HRmax% RR	(21.03→29.03) (34.79→36.27) (64.92→78.66) (24.30→27.53) (unloaded →loaded)
Godhe et al., 2020	35, 50 kg rucksack	Treadmill walking speeds 3 & 5 km/h	VO2max% (20,35,50)	(22.5, 26, 35) (3 km/h) (31, 40.5, 50.5) (5 km/h)
Bach et al., 2017	EOD PPE	Standing & Treadmill walking speeds 2.5, 4.0, & 5.5 km/h	Metabolic Rate (W)	(118, 389, 549, 795) (stand, 2.5, 4.0, 5.5)

Findings Supporting Increased Metabolic Demand and the need for Aerobic Fitness

Energy expenditure (EE) is a factor that influences an athlete's work capacity, and current studies conclusively support that carrying heavy loads increases energy expenditure (Godhe et al., 2020; Knapick et al., 2004; Mala et al., 2015). Researchers have outlined the importance of predicting the metabolic demand of tactical athletes (Friedl et al, Williams et al, Drain et al), and several authors have worked to create and validate/critique the Pandolf equation; which predicts metabolic demand using body weight, load, speed, grade, and terrain (Brown et al., 2012; Drain et al, 2017; Majumdar et al., 1997). At grades up to 30% and loads ranging from 0 to 30 kg, the equation was accurate at 4 km/h but underestimated energy expenditure at 2.4 km/h. With the same load and speed but on a level treadmill, the equation underestimated metabolic rate by 14–33% (Drain et al., 2017). In a different study, the equation's validity with different combinations of equipment and a wide range of speeds was assessed (Drain et al., 2016). In another study, soldiers walked with 22.7 and 38.4 kg (26% and 45%BW) at three different speeds: speeds replicating walking and approach march speeds, and the movement necessary while engaged (five 30-m sprints commencing every 44 seconds and sixteen 6-m bounds commencing every 20 seconds) (Billing et al., 2015). The Pandolf equation significantly underestimated EE for all conditions, especially at the walking and engagement speeds.

The tactical athlete's ability to carry a load in the field while minimizing physiological fatigue is multivariate, and literature indicates that VO2 max and the duration of the task are the strongest predictors of load carriage performance. This conclusion is consistent with the previously stated claims (Robinson et al., 2018). Overall relationships between intensity and volume remain similar under load as they are without load: As duration of activity increases, the intensity of exercise that can be sustained decreases, and conversely, higher intensity exercise results in a shorted time to exhaustion. At walking speeds, VO2 can be largely derived from ambulation speed and load carried. As speed and load increase, there is an elevation in HR, oxygen uptake, EE, blood lactate concentrations, and ventilatory rate (Christie & Scott, 2005; Beekley et al., 2007; Godhe et al., 2020; Kobus et al., 2010). Table 2 organizes and displays some of the data recorded by metabolic cart testing.

Table 2: Loads Carried and Metabolic Data Captured by Previous Studies

Author	Load Carried	Speed (km/h)	Average VO2 (mL/kg/min)	Average HR (BPM)	RPE	RER
Kobus et al	0, 44.5, and 61 kg	3.2	13.8, 19, 23	91.2, 114.7, 129.6	N/A	N/A
Beekley et al	30, 50, and 70% of lean body mass	6	20, 22, 29	120, 138, 159	(Borg) 11, 12, 14	.86, .89, .93
Christe et al	20, 35, 50, and 65 kg	3.5, 4.5, 5.5, and 6.5				
Godhe et al	20, 35, and 50 kg	3, 5	(values in % of VO2 max) 3 km/h; 22.5, 26, 35 5 km/h; 31, 40.5, 50.5	N/A	N/A	N/A

Steady state performances are aerobic performances that occur at a manageable intensity for extended durations of time and are considered good markers of aerobic fitness (Foster et al., 2015). In 2014, a dissertation was published wherein nine ROTC subjects were studied during a 30 kg loaded march over the course of two hours (Krajewski, 2014). The author found that the studied variables (VO2, VCO2, RER) did not increase over the two-hour period once steady state was achieved. This supports previously discussed findings that highlight the importance of a strong aerobic base for load carriage performance, making the case again for cardiovascular fitness as an indicator of load carriage readiness.

In another load carriage study, the one RM bench press, back squat, deadlift, pull up, vertical jump, 10m sprint, beep test, and the loaded 5k time trial protocol (3 separate trials separated by 3-4 months) were studied in 42 police officers (Robinson et al., 2018). The researchers analyzed these results along with anthropometric data from the subjects to determine which values had the greatest correlation with load carriage performance. Results indicated that for all measures of strength, relative strength was better correlated to performance than absolute strength (see table 3), as represented by movement correlation (i.e. max squat) versus movement relative to bodyweight correlation (i.e. squat ratio %). Further, as the speed of the trials increased the researchers found a decrease in the correlation between the strength measures and the loaded performance. They found no differences in levels of correlation between the shuttle run and all three of the progressively faster load carriage trials. The results of their study support that strength is significantly and moderately correlated with load carriage performance, but that aerobic fitness, as measured by the beep test, had the highest correlation with all load carriage events ($r = -0.712$, -0.709 and -0.711 for trials respectively).

Table 3: Correlations between load carriage performances over three 5 km time trials 3-4 months apart and baseline measures by Robinson et al., 2018

Measure	**Time Trial 1**	**Time Trail 2**	**Time Trial 3**
Time Trial 1 (mins:sec)	1	.840**	.815**
Time Trial 2 (mins:sec)	.840**	1	.881**
Time Trial 3 (mins:sec)	.815**	.881**	1
Body Weight (kg)	.097	.010	.081
1 RM Bench Press (kg)	−.360*	−.318*	−.295*
Bench Ratio (%)	−.465**	−.365**	−.379**
1 RM Squat (kg)	−.401**	−.335*	−.316*
Squat Ratio (%)	−.500**	−.381**	−.396**
1 RM Deadlift (kg)	−.288*	−.248	−.215
Deadlift Ratio (%)	−.403**	−.294*	−.305*
1RM Pull-up (kg)	−.452**	−.439**	−.416**
Pull-up Ratio (%)	−.607**	−.512**	−.541**
Vertical Jump (cm)	−.501**	−.541**	−.523**
Shuttle Run (level)	−.712**	−.709**	−.711**

**Correlation is significant at the 0.01 level (2-tailed).*
***Correlation is significant at the 0.05 level (2-tailed)*
Source: Robinson, J., Roberts, A., Irving, S., & Orr, R. (2018). Aerobic Fitness is of Greater Importance than Strength and Power in the Load Carriage Performance of Specialist Police. International journal of exercise science, 11(4), 987–998.

Review of the Importance of Strength

A study found that lower-body strength and power were consistently reduced directly following or during load carriage tasks (Dempsey et al., 2013). This study used a VO2 max test, a balance task, an acceleration task that simulated exiting a vehicle, chin-ups, a grappling task, and a maneuverability task. A 5-min treadmill run (zero-incline at 13 $km \cdot h^{-1}$, running start) was then completed. One minute after the run, the five mobility tasks were repeated. Results showed a significantly decreased performance in each test with a 1.5 kg stab resistant vest. These results are made more significant by an understanding of the load-speed index. A different study used six investigations of loaded marches to derive a predictor known as the Load-Speed Index of a certain load's effect on VO2 (Boffey et al., 2019).

$$\text{Load-Speed Index} = \text{Speed (km/h)} \cdot \text{Load (\%BW)}$$

The researchers used a linear regression to check their equation against existing research, and a significant correlation was found between load-speed index and percent of VO2 max. Further, the load-speed index accounted for 86.8% of the variance (r^2). With these principles, we should be able to conclude that strength (the ability to work against/under load proportional to body mass) should increase the ability to carry load at faster speeds. It is common to cite the potential influence of familiarization on a study's testing procedures. A previously mentioned study cites experience with load carriage as one of the strongest variables that influences load carriage performance, alongside body composition and VO2 max (Godhe et al., 2020). This is one of the boons of load carriage-specific training, and it is beneficial for performance at some level regardless of other details pertaining to the training programming. This does leave a large margin for

variability in other facets, and literature currently supports concurrent training for load carriage involving a mixture of load carriage, cardio-vascular, and strength training. One study prescribes a type of programming that maximizes power development while maintaining some form of aerobic base (Mala et al., 2015). The researchers argue that the battlefield has shifted from an aerobic one to an anaerobic, and the need for quick, explosive movement has increased exponentially. The researchers state that vehicular transportation has taken the place of long marches, and that once infantry arrive on-site, they must sprint, lift, carry, climb, push, and pull while carrying significant loads.
Two researcher's testing on individuals with various loads (no load, 9 kg, 17 kg, 29 kg, and 36 kg in the form of a framed rucksack system) over obstacle courses showed similar results, where faster performers had greater upper body strength and power than slower performers, and absolute strength measures were predictive of criterion military task performance (Martin, Nelson, 1986). Greater upper and lower body strength and power have been shown to be beneficial for the optimal performance of high-intensity combat tasks (Godhe et al., 2020; Mala et al., 2015), making an argument for the importance of strength and power for load carriage.

Fire Fighting Load Carriage

Outside of the above literature, there is a body of research that devotes itself to the loads carried by firefighting personnel, which is typically lighter than EOD gear but includes a similar SCBA unit, and is most likely similarly taxing in terms of thermoregulation, due to the thick material worn and the high coverage provided by said material. In 2018, researchers performed the first field study that measured the metabolic demand of hiking during wildland firefighter (WLFF) training and wildfire suppression (Sol et al., 2018). The researchers used global positioning system (GPS) tracking, heart rate, internal temperature, speed, and elevation gain with the Pandolf equation to predict oxygen uptake. Equipment through the study varied by crew type, where WLFF personnel either carried a 24±9 kg or 28±6 kg load, allocated as a pack, equipment, and tools. This Pandolf equation was one of the first devised equations to predict energy expenditure while standing or walking uphill or downhill while loaded (Pimental & Pandolf, 1979). While this equation may under predict demand, the WLFF study concluded that WLFFs have the highest rate of energy expenditure during ingress hikes, which were 20 minutes in duration at 2.9 km/h and 4% grade on average. Further, there was a high variation in hike duration and grade, where 40% of hikes were less than ten minutes and 18% of hikes were longer than 30 minutes.

EOD Load Carriage

The Pandolf equation was shown again to underestimate load carriage demand by a study that utilized a progressive treadmill walk and indirect calorimetry. This study utilized EOD gear for the first time in this context, and found that walking at 2.5, 4.0, and 5.5 km/h was significantly more metabolically demanding while walking with EOD PPE than without ($p<.05$) (Bach et al., 2017). A more comprehensive and fieldwork-based study was performed that also showed an increase of metabolic demand in terms of VO2 consumed, but this study was performed through an obstacle course including hurdles, stairs, an incline and decline ramp, and walking (Wu et al., 2022). This study seems to be the first of its kind in its attempt to quantify the increased demand during field tasks and made significant headway in filling the gap in existing load carriage research. The present study will seek to expand upon these findings by determining which factors alter the increased metabolic demand brought on by wearing EOD PPE.

Discussion

Most of the above-mentioned literature has been derived from research concerning non-EOD personnel. Explosive ordinance disposal personnel gear has been shown to be more metabolically demanding than most PPE, but relationships between power and the mitigation of this demand have not yet been explored. Further, EOD research has yet to explore the effect of incline on walking metabolism. EOD gear is also most likely more restrictive on motion and is less accommodating to the user's body temperature and regulation thereof (Wu et al., 2022). A relative lack of research exists around EOD gear and its effects on metabolic demand, strength requirements, and the factors that improve mobility and performance. To this point, predictions concerning how metabolically taxing wearing the gear is have been almost exclusively extrapolations from the existing literature built around the infantry soldier.

Current literature cites aerobic fitness as a strong predictor for load carriage, but this may not hold true for loads like the EOD gear. More vigorous studies have utilized loads as heavy as 50 kg (Godhe et al., 2020), which should serve as a similar stimulus in terms of raw load, but the distribution of weight characterized by the EOD gear presents challenges to mobility and thermoregulation, which could have non-zero effects on overall performance. It is also possible that EOD gear will have the same effect on performance as infantry loads do, and that our current extrapolation of results from one intervention to the other is appropriate, but we need to establish that this assumption is feasible/appropriate.

Most of the literature cites the importance of aerobic fitness above that of strength (Mala et al., 2015; Knapick et al., 2004; Robinson et al., 2018), but EOD gear is significantly heavier and more pervasive in an individual’s movement patterns. Strength is the ability to work against resistance, so it seems intuitively possible that load carriage involving greater resistance should require more strength. However, the discussed literature has affirmed that as the load carried increases, so does metabolic demand, thus increasing the need for high aerobic work capacity (Stewart et al., 2011).

There seems to be a gap in the literature surrounding the importance of strength for heavy load carriage, especially in its relationship to the increased metabolic demand. Dempsey et al 2013 and their load-speed index devised a way to predict the effect of load on speed, but did not deeply investigate the importance of strength against heavy load. Strength as the ability to navigate resistance intuitively has great value where resistance is directly causing decreased field performance, and as this resistance increases, there is a need to understand its effect on EOD personnel.

III. Methods

The research problem was investigated via a crossover experimental design, where subjects acted as their own control. On two separate visits, subjects first completed a familiarization protocol in standard exercise clothes, then at least one week later a nearly identical protocol with the exception of a modified treadmill protocol and the addition of EOD gear.

Methodology

Role in the Larger Study

This study was performed as part of a larger study which also seeks to quantify the increased metabolic demand required by load carriage. The larger study's methodology will be outlined below to illuminate the entire testing protocol, and to give context towards what was asked of the subjects. The metrics utilized in the present study will be outlined at the end of the methodology section. This study was approved by the Institutional Review Board.

Subject Entrance Criteria

Subject were not allowed to participate in the study if they exhibited any contraindications for exercise. These include existing heart conditions/high blood pressure (greater than 140/90 without doctor's notice), angina during activities of daily living, or current muscular-skeletal injury. Subjects completed a pre-exercise testing questionnaire before beginning testing, which included an on-site BP check, and assisted in excluding subjects unfit for testing. Due to the adjustable nature of the gear, subjects between the heights of 150 and 210 cm were considered valid subjects.

Sample Information

The sample size of this study was a minimum of 12 for a power of .80, as calculated via statistical power test, which is consistent with similar load carriage studies (Bach et al., 2017; Wu et al., 2022). This study successfully recruited a sample size of 15.

Testing Scheme

Each testing visit utilized an ABA format, wherein the subject completed a set of pre and post tests (A) and a more central testing battery (B). This was to assess the overall changes in cognitive function, major and minor strength, and total cardiac drift brought on by the central testing battery, which included the main intervention (the load carried or not carried).

Test Battery A (Pre)

Test Battery A utilized a selection of assessments that ensured the subjects were safe to test, and supply a set of baselines that could be used to compare with post-test results. These assessments were both physical and mental in nature, as both are necessary for performance in the field, and possibly affected by load carriage.

The testing protocol began with a preliminary health questionnaire and consent form. After this is completed, the familiarization testing began by assessing resting blood pressure and heart rate with an Omron blood pressure monitor on the right arm while the subject was in a seated position (Tholl et al., 2004). Body weight (BW), fat percentage (BF%), and total body water (TBW) were measured via Tanita SC-331S standing scale (Japan), where age, height, and sex were entered, and athletic builds assumed. TBW, BF%, intracellular fluid (ICF), and extracellular fluid (ECF) were measured via Impedimed SOZO body composition analyzer (Pinkinba, Australia), and body temperature via an infrared forehead thermometer (Finicare Model FC-IR200, China). After this, subjects completed a reaction time test via computer program PsychoPy, a handgrip test via a Takei handgrip dynamometer (Japan), vertical jump test (full countermovement jump) via a Just Jump mat (Probotics inc., Huntsville, Alabama), and max isometric rack pull via force plate (Rice Lake (Wisconsin) floor scale, utilizing a National Instruments daq and custom LabVIEW (Austin, Texas) software). During the Isometric rack pull, a barbell was chained to a squat rack at 71 cm, and subjects were instructed to step up to the bar, remove the slack from the chain, and pull until their force output (as measured by the force plate) faltered or they felt they had to stop. During the handgrip test, subjects were instructed to hold the dynamometer (set at setting six) and squeeze as hard as possible for 5 seconds.

At this point in the protocol for the EOD visit, the EOD gear was be appended to the subject starting with the chaps, followed by the integrated groin protection, followed by the helmet, and lastly followed by the jacket. Once suited up, the helmet was plugged in and an integrated air conditioning unit was activated. For the familiarization visit, the subject remained in gym clothes.

Testing Battery B

Testing Battery B is the portion of the methodology that utilized the interventions and the accompanying modification of the Bruce treadmill protocol. This portion of the protocol was the most rigorous and assessed the subject's performance in terms of strength, power, endurance, and overall ability to perform field-relevant duties.

At this stage in the protocol, subjects stepped over a bar set at 71 centimeters and rated their RPE on a scale of 1-10. The bar step-over was followed by a stair sprint consisting of 27 stairs and a total of 4.8 meters of elevation gain. After this, a sled drag was performed with a Spud Inc. canvas weight sled, loaded with 180 pounds and pulled with a handle and chain attachment while facing the sled (moving backwards). This drag was performed for 18.29 meters, and the 9.14-meter split recorded. After this a 9.14-meter sprint, 9.14-meter hands crawl, and a 9.14-meter belly crawl was performed, with ample rest between bouts. After this, subjects began their metabolic cart testing.

A ParvoMedics TrueOne metabolic system was used to measure VO2/kg, respiratory exchange ratio, and heart rate (via a Polar chest HR monitor) while the subject ambulated on a Woodway treadmill. During the familiarization visit, a full Bruce VO2 max procedure was utilized to determine VO2 max, where subjects experienced increasing speed and incline every 3 minutes until they ended the test. During the EOD visit, subjects performed the same protocol but after the 3.4 miles per hour, 14% grade was held for 3 minutes, they moved back down to the 2.5 mph and 12% grade stage for 6 minutes, after which the test was concluded. At one-minute intervals throughout the duration of the test, subject-reported RPE was recorded.

Table 4: Bruce Treadmill Protocol

Speed (mph)	Incline (grade)	Duration (min)
1.7	0	3
1.7	10	3
2.5	12	3
3.4	14	3
4.2	16	3
5.0	18	3
5.5	20	3
6.0	22	3

Table 5: Modified Bruce Protocol

Speed (mph)	Incline (grade)	Duration (min)
1.7	0	3 min
1.7	10	3 min
2.5	12	3 min
3.4	14	3 min
2.5	12	6 min

Testing Battery A (Post)

The post-testing version of test battery A utilized the addition of the digit countback, but was otherwise identical to the previous test battery A both in terms of the tests performed and the manner in which they were performed. Post-testing served to quantify how the intervention reviewed in testing battery B affects mental and physical performance variables.

Directly after the treadmill testing, subjects removed the EOD gear during the EOD gear visit and body temperature was re-recorded. Rest between assessments was no longer than two minutes, and subjects were allowed to hydrate with water ad-libitum, where the volumes were recorded. After this recovery period, post vertical jump, hand grip, and maximum isometric rack pull were recorded. After these, a Digit Countback short term memory test was administered via the PsychoPy software. Finally, post reaction time, resting blood pressure and heart rate (to assess total cardiac drift), and body composition were recorded. All post-testing was performed with methods identical to their pre-testing counterparts.

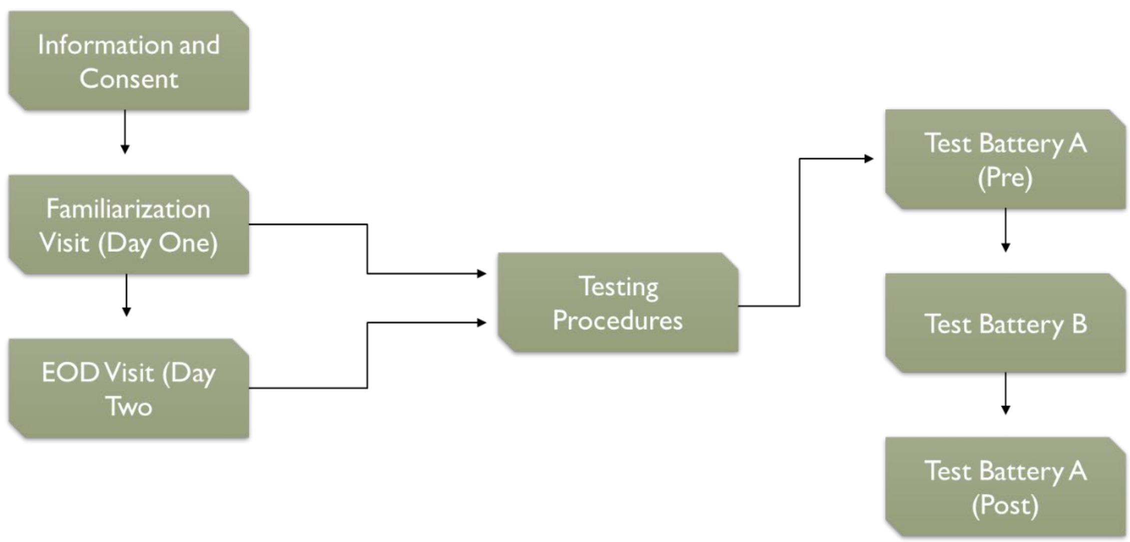

Figure 1: Scheme of Testing Design

The Present Study

Of the above measurements, the present study only analyzed the results of the loaded and unloaded Bruce protocol, FAM stair sprint, FAM sled pull, FAM isometric rack pull, and FAM body composition data. These measurements should be sufficient to illuminate any potential relationships between strength, power, and endurance and the increased metabolic demand imposed by EOD load carriage.

Analysis

These testing procedures quantitatively assessed anaerobic power and aerobic performance with methods consistent with standards reviewed by the exercise science field (Godhe et al., 2020; Krajewski, 2014; Wu et al., 2022). Quantitative data is ideal for the research because of its ability to be statistically analyzed for objective differences between the testing groups. The protocol outlined above measures body composition, blood pressure, HR, temperature, maximal strength, maximal power, power over time, and aerobic capacity. These attributes are all part of the multivariate problem that is load carriage (Godhe et al., 2020; Robinson et al., 2018). Subjects were selected via convenience sampling, and subjects needed to be relatively fit to be able to safely complete the testing procedures. Results were pulled from data sheets and the Eastern Kentucky University Exercise Physiology Lab computer and put into an Excel sheet (Microsoft, 2016, Redmond, Washington), where means, ranges, T-tests, and a power test were used to analyze the results.

The research design draws from methodologies present in similar accredited load carriage research (Bastien et al., 2005; Blacker et al., 2003; Robinson et al., 2018). The apparatus used for the isometric rack pull and VO2 testing meet the highest standards set by existing literature in terms of accuracy (Keren et al., 1980; Spudić et al., 2021), and all other methods of data collection meet conventional standards of research. Potentially unreliable measures included the hand timing of the stair and 9.14-meter sprint, sled pull, and crawls, but hand timing is a commonly used methodology due to its ease of access and accuracy (Mala et al., 2015). Measures are internally valid because the protocol remained the same, and the same apparatus was used per measurement regardless of subject or intervention (with the exception of the load carried). Measurements are externally valid because of the use of similar testing procedures in accredited literature, and due to testing procedures mimicking field environments for EOD personnel (Godhe et al., 2020; Krajewski, 2014; Majumdar et al., 1997). A second area for assessment error may be temperature via forehead thermometer. This method was chosen due to its cost effectiveness and served as an area of exploration for the larger study, which will use more valid thermometers in a later iteration. Temperature data was not analyzed as part of the present sub-study. The research should be viewed as credible to others because of the above-mentioned validity, reliability, and rigor, and future researchers should be able to replicate the research plan due to its simplicity and clear methodology.

The study needed to utilize at least 12 subjects to achieve a power of 0.81, set at a significance of 0.05. This was determined using a T-test sample size calculator, where a large effect size was assumed, as was supported by pilot work. For a correlation to be significant at the $P<0.01$ level, that correlation had to be $P=.606$ or larger. In addition to means and average changes from unloaded performances to their loaded counterparts, A correlation matrix was also be derived, similar to the one presented by Robinson et al., 2017 in Table 3.

Outcomes

Results will likely indicate that wearing the EOD gear increases metabolic demand. This will be consistent with other load carriage research findings (Bastien et al., 2005; Blacker et al., 2003; Boffey et al., 2019). Specifically, results will likely show an even greater metabolic demand than infantry load carriage, which is the subject of most existing literature, replicating the findings of previous studies (Bach et al., 2017, Wu et al., 2022). There may also be correlation between strength as measured by the isometric clean pull and sled pull and an upregulation in HR, VO2, or RER to account for the increased metabolic demand. Results may implicate a correlation between body mass and the degree of metabolic increase, as the added mass of the load would make up a lower percentage of the total mass the body has to move for larger individuals, and this may hold especially true when we consider the amount of lean mass in comparison to fat mass. Lastly, we may be able to draw correlations between individual markers of fitness and overall EOD load carriage performance. These possible findings could help guide training programming for EOD personnel, and create and landmark upon which further literature concerning specialized load carriage may be written.

IV. Results

Fifteen subjects completed the study, and had an average age of 23.4±5.00, height of 176.6±6.87 (cm), and weight of 90.10±15.11 (kg) (mean ± standard deviation). From the familiarization tests, the subjects had an average VO2 max of 35.507±11.29 (mL/kg/min), isometric rack pull of 163.27±42.78 (kg), stair sprint time of 6.07±1.17 (sec), and sled pull time of 11.52±3.22 (sec). From the EOD visits, the average stair sprint time was 10.60±3.30 seconds, and the average sled pull time was 14.20±3.28 seconds. For the treadmill portion of the testing, there were significant differences between the FAM and EOD trials. On average, subjects lasted 14.4±2.82 minutes during FAM, and 9.6±2.87 during EOD. Between the EOD and FAM visits, average change for HR was 24.87±11.04 BPM in stage one, 38.14±10.47 BPM in stage two, and 41.6±15.91 BPM in stage three. For RPE, average change was 2.27±1.69 (1-10 AU) for stage one, 3.14±1.25 (1-10 AU) for stage two, and 3.92±1.44 (1-10 AU) for stage three. For RER, average change was -.01±.107 for stage one, .06±.06 for stage two, and .13±.07 for stage 3. For VO2, average changes were 3.79±2.83 mL/kg/min for stage one, 7.2±3.67 mL/kg/min for stage two, and 9.81±10.91 mL/kg/min for stage three.

Table 6: Mean ± Std Dev for HR, RPE, RER, and VO2 over the FAM and EOD treadmill protocol

	Stage 1	Stage 2	Stage 3
FAM HR (BPM)	110.87±15.28	125.53±14.38	144.73±18.44
EOD HR (BPM)	135.73±14.64**	161.71±9.32**	181.3±6.57**
FAM RPE (1-10)	.93±.44	1.87±1.02	3.07±1.95
EOD RPE (1-10)	3.20±1.68**	5.00±1.77**	6.60±2.24**
FAM RER	.84±.11	.75±.06	.82±.05
EOD RER	.84±.07	.85±.06**	.94±.08**
EOD VO2 (mL/kg/min)	7.51±2.33	12.3±3.44	17.53±4.04
EOD VO2 (mL/kg/min)	11.31±3.46*	19.46±3.21**	30.18±2.16**

*= Significantly different from FAM at P<0.05
**= Significantly different from FAM at P<0.01

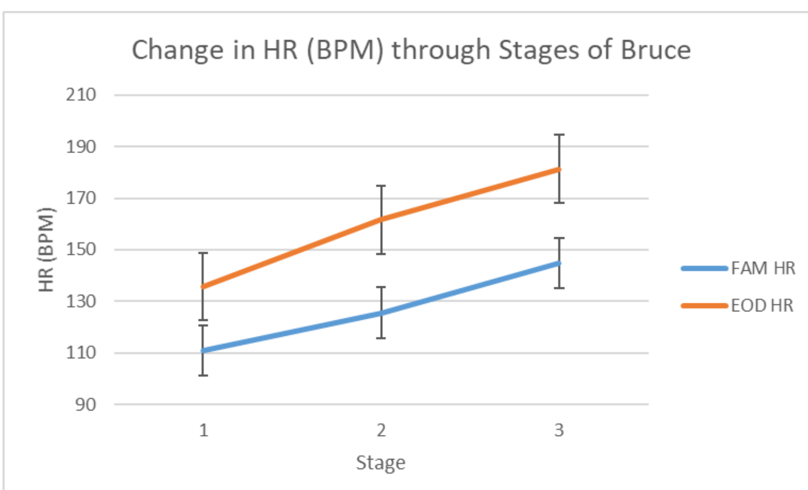

Figure 2: HR changes through the progression of the Bruce protocol

Figure 2 shows the increase in HR through the three stages of the Bruce protocol during the EOD and FAM visits, with error bars appended. The data displays the significant difference between stages 1, 2, and 3 (P<0.01), and that the difference may get larger as the Bruce protocol gets more difficult.

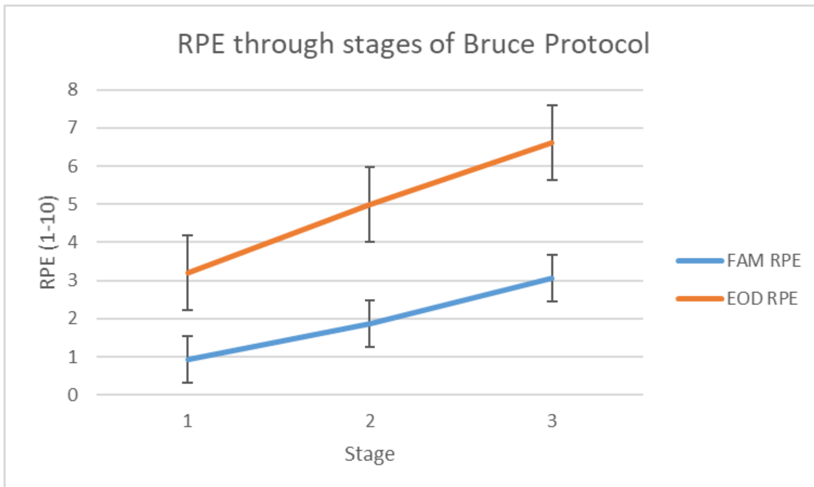

Figure 3: RPE changes through the progression of the Bruce protocol

Figure 3 shows the increase in RPE through the three stages of the Bruce protocol during the EOD and FAM visits, with error bars appended. The data displays the significant difference between stages 1, 2, and 3 (P<0.01), and that the difference may get larger as the Bruce protocol gets more difficult.

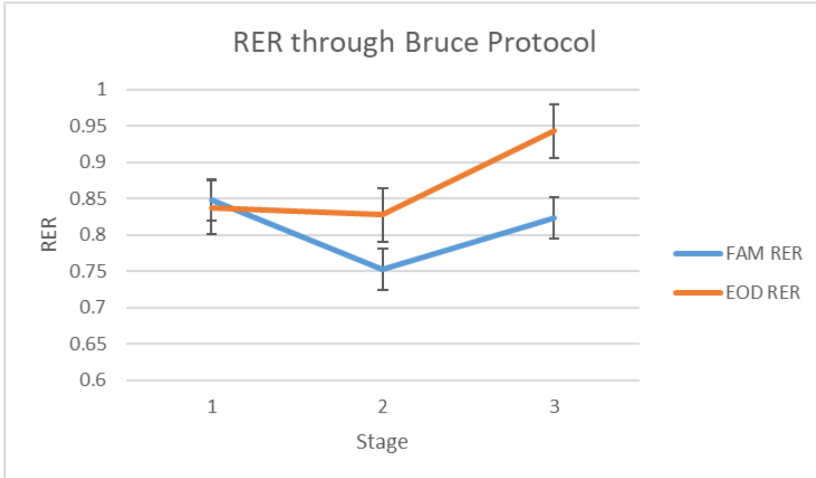

Figure 4: RER changes through the progression of the Bruce protocol

Figure 4 shows the increase in RER through the three stages of the Bruce protocol during the EOD and FAM visits, with error bars appended. The data shows no difference in stage one, and a larger and significant difference between visits in stages 2 and 3 ($P<0.01$).

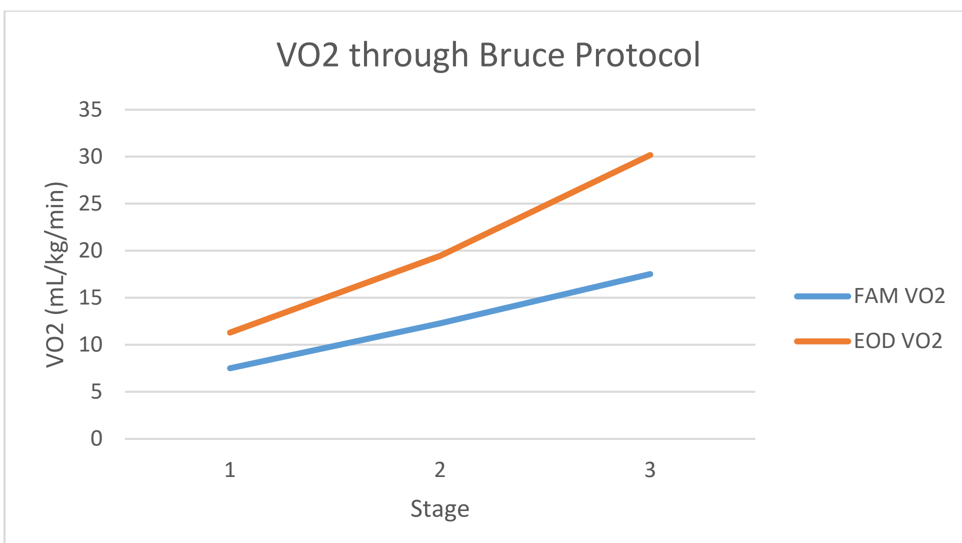

Figure 5: VO2 changes through the progression of the Bruce protocol

Figure 5 shows the increase in VO2 through the three stages of the Bruce protocol during the EOD and FAM visits, with error bars appended. The data shows that as the Bruce protocol got more difficult the difference in VO2 uptake became larger. Stage 1 was significant at $P<0.05$, while stages 2 and 3 were significant at $P<0.01$.

Changes in Metabolic Demand between the FAM and EOD Bruce Protocols Correlated to Performance Variables

Table 7: FAM Measures of Performance

	FAM Rack Pull (kg)	FAM Stair Sprint (sec)	FAM Sled Pull (sec)	VO2 max (mL/kg/min)
Average	163.42	6.07	11.52	35.51
St. Dev.	42.72	1.17	3.22	11.30
Maximum	211.27	8.57	19.88	52.5
Minimum	50.51	4.65	7.48	16

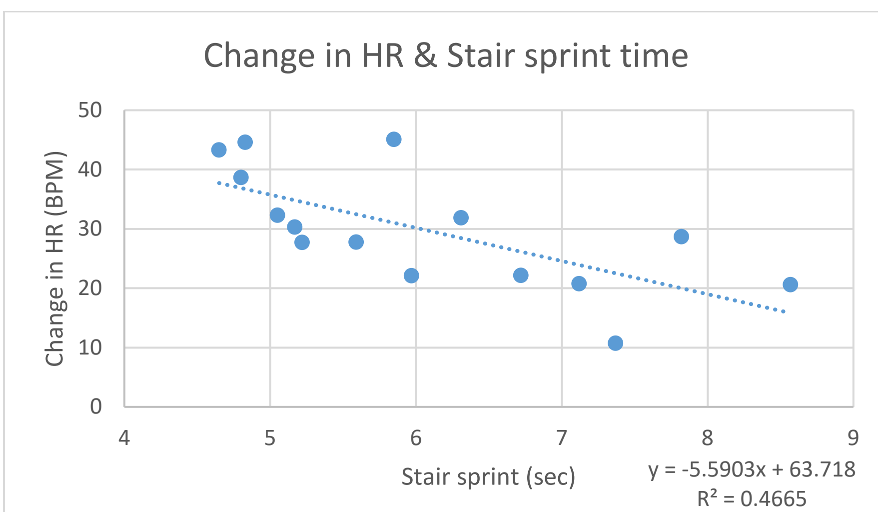

Figure 6: Change in HR (BPM) correlated to stair sprint time

Figure 6 shows a significant negative correlation (R=-0.683) ($P< 0.01$) between stair sprint time (sec) and change in HR (BPM) necessary to sustain EOD load carriage. The data suggests that subjects upregulated with a greater HR increase through the Bruce protocol while wearing the EOD gear.

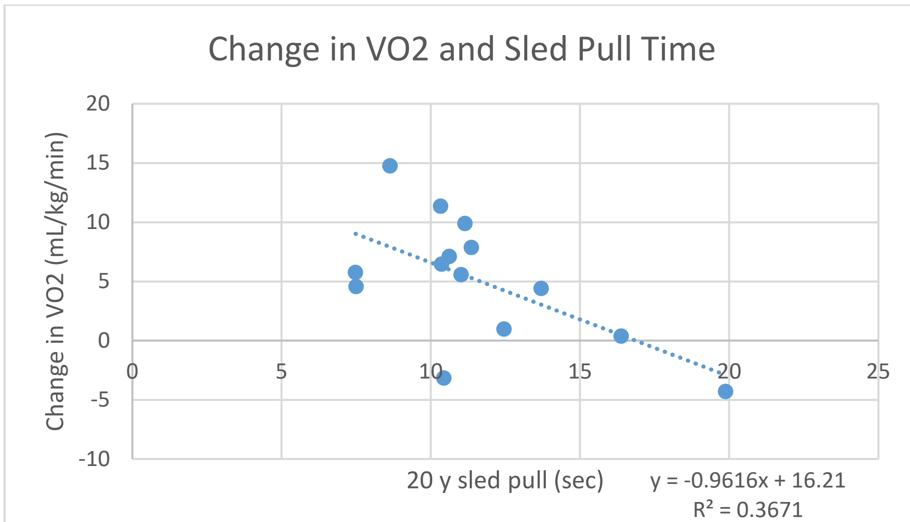

Figure 7: Change in VO2 correlated to sled pull time

Figure 7 shows a significant negative correlation (R=-606) ($P<0.01$) between sled pull time and the change in oxygen needed to sustain EOD load carriage through the Bruce protocol. The data suggests that subjects with a faster sled pull time upregulated more in terms of VO2 consumption while wearing the EOD gear.

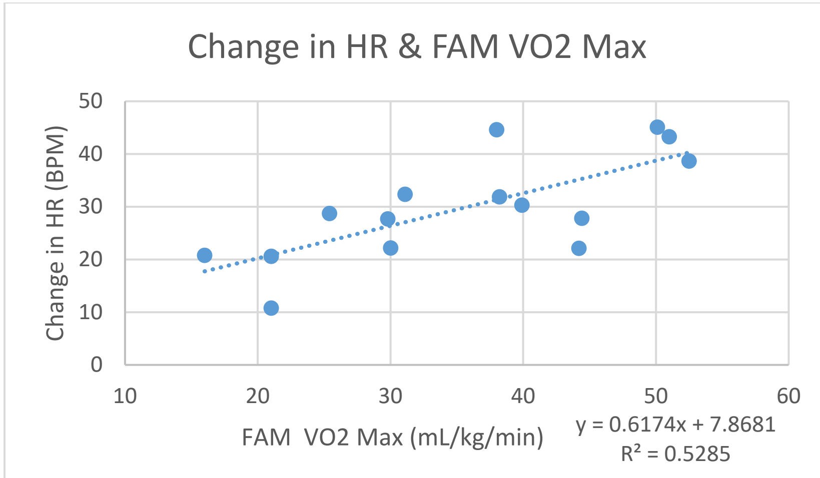

Figure 8: Change in HR correlated with FAM measure of VO2 max

Figure 8 shows a strong significant positive correlation (R=.727) (P<0.01) between the subject's VO2 max and the change in HR necessary to sustain EOD load carriage. The data suggests that subjects with higher VO2 max measures upregulated more through the EOD Bruce protocol in terms of HR.

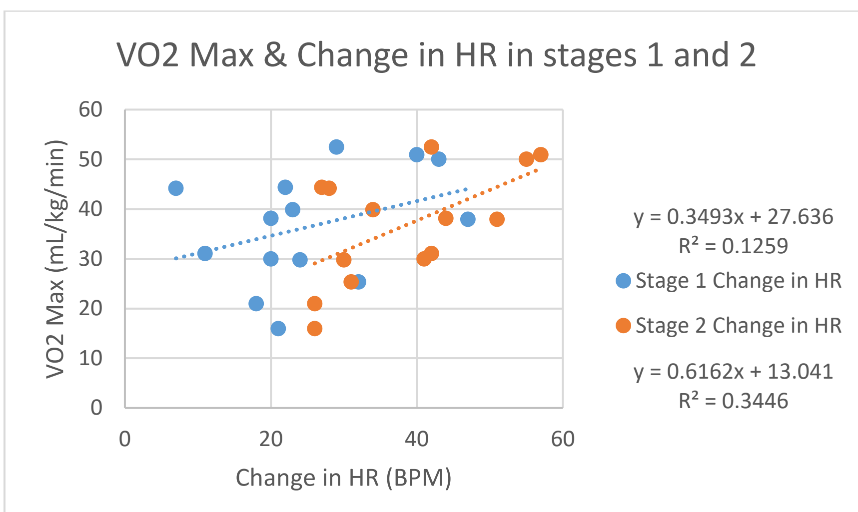

Figure 9: Change in HR correlated with FAM VO2 max in the first two stages of the Bruce protocol

Figure 9 shows the correlation between VO2 max and change in HR on a stage by stage level, where R=.355 and .587 for stages one and two, respectively. The correlation at stage two was significant, while stage one was not ($P<0.05$)

Table 8: Correlation matrix for measured metabolic variables

	Change in HR (BPM)	Change in RPE (1-10 AU)	Change in RER	Change in VO2 (mL/kg/min)
FAM Stair Sprint	-0.683**	-0.040	0.137	-0.518*
FAM Sled Pull	-0.538*	0.336	0.269	-0.606**
FAM Rack Pull	0.569*	-0.567*	-0.354	0.323
FAM VO2 max	0.727**	-0.214	-0.065	0.376

*Significant at ($P<0.05$)
**Significant at ($P<0.01$)

Correlations Concerning Bruce Protocol Duration

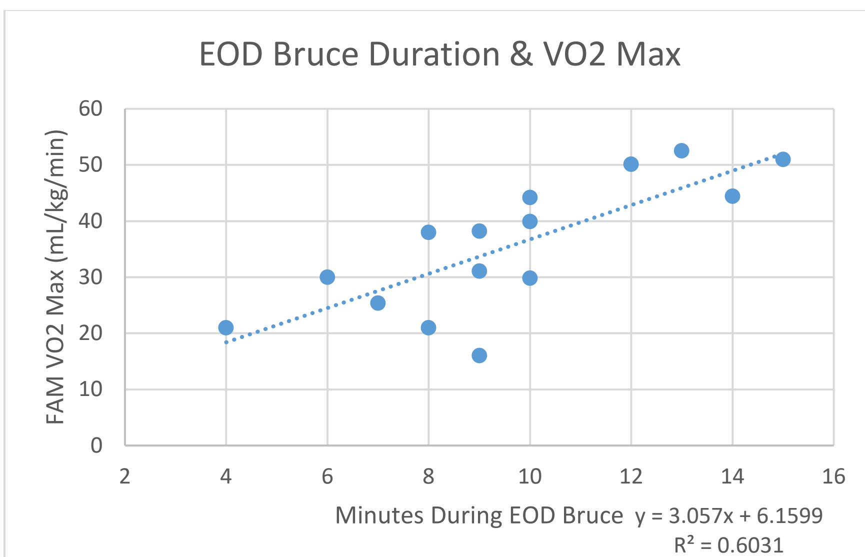

Figure 10: Correlation between subjects' VO2 max and their EOD Bruce progression

Figure 10 shows a significant positive correlation (R=.78) ($P<0.01$) between a subjects' VO2 max measurement and the minutes they were able to progress through the Bruce protocol while wearing the EOD suit. The data suggests that subjects with a greater VO2 max measurement were able to progress further through the EOD Bruce protocol.

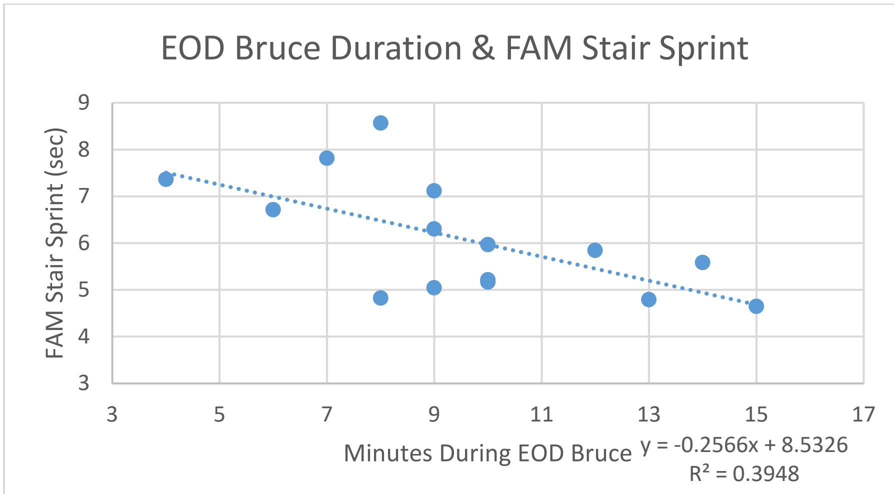

Figure 11: Correlation between subjects' FAM stair sprint time and their EOD Bruce progression

Figure 11 shows a significant negative correlation (R=-.63) ($P<0.01$) between subjects' stair sprint time and the time subjects were able to progress on during the Bruce protocol wearing the EOD suit. The data suggests that subjects capable of a faster stair sprint were capable of progressing further through the EOD Bruce protocol.

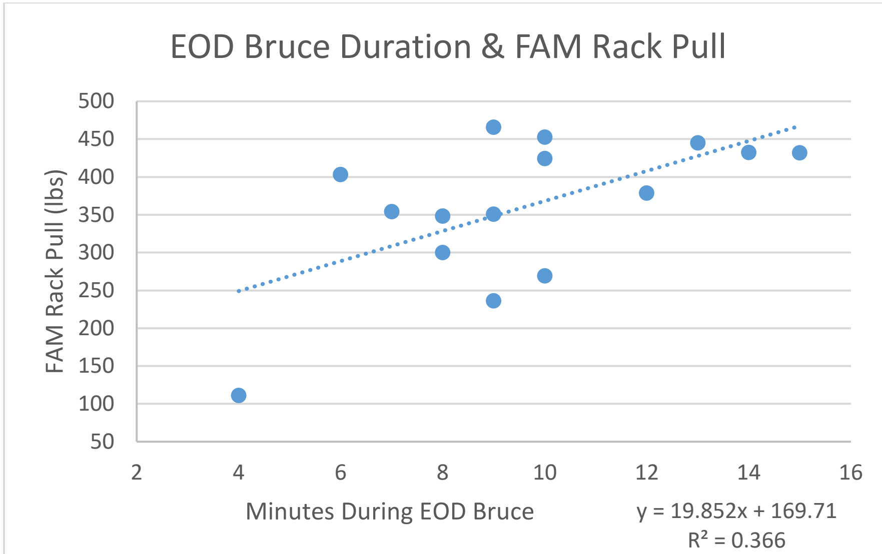

Figure 12: Correlation between subjects' FAM rack pull and their EOD Bruce progression

Figure 12 shows a significant positive correlation (R=.61) (P<0.01) between subjects' rack pull force in pounds and the time they progressed through the Bruce protocol. It is worth noting that removing the outlier seen at 4 minutes and 111 pounds reduces the correlation to R=.39, which is insignificant. The data suggests that stronger subjects as measured by isometric rack pull were able to progress further through the EOD Bruce protocol.

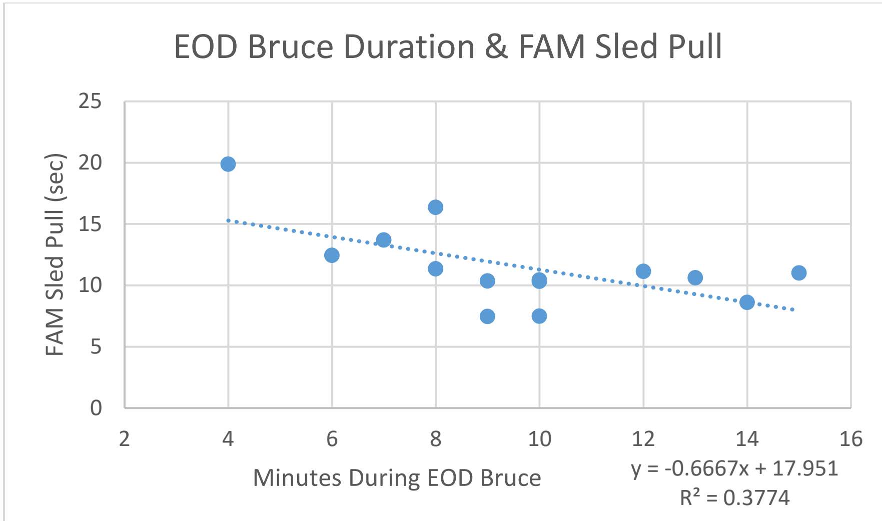

Figure 13: Correlation between subjects' FAM sled pull and their EOD Bruce progression

Figure 13 shows a significant negative correlation (R=-.61) (P<0.01) between subjects' sled pull time and the time subjects were able to progress on the Bruce protocol in the EOD suit. The data suggests that subjects capable of a faster sled pull were also more capable of progressing further through the EOD Bruce protocol.

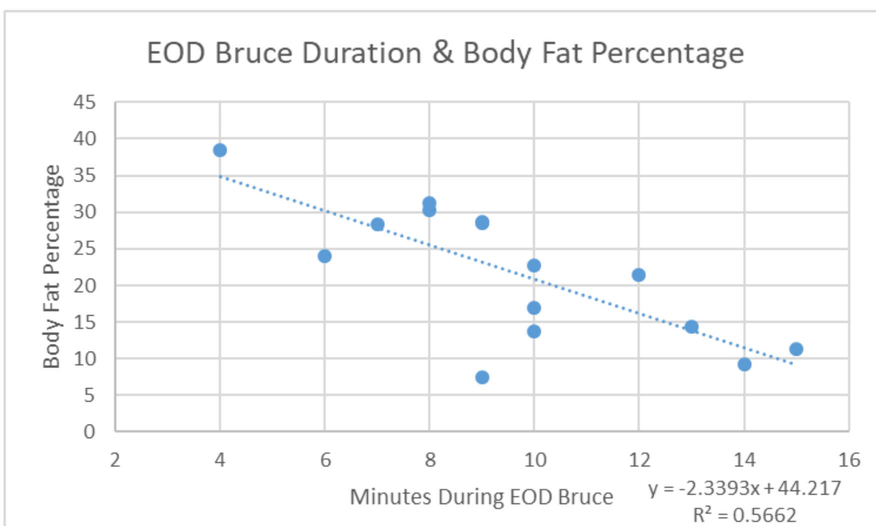

Figure 14: Correlation between subjects' body fat percentage and their EOD Bruce progression

Figure 14 shows a significant negative correlation (R=-.75) (P<0.01) between subjects' body fat percentage as measured by the Tanita and the time they were able to progress on through the Bruce treadmill protocol. The data suggests that leaner subjects were able to progress further through the EOD Bruce protocol.

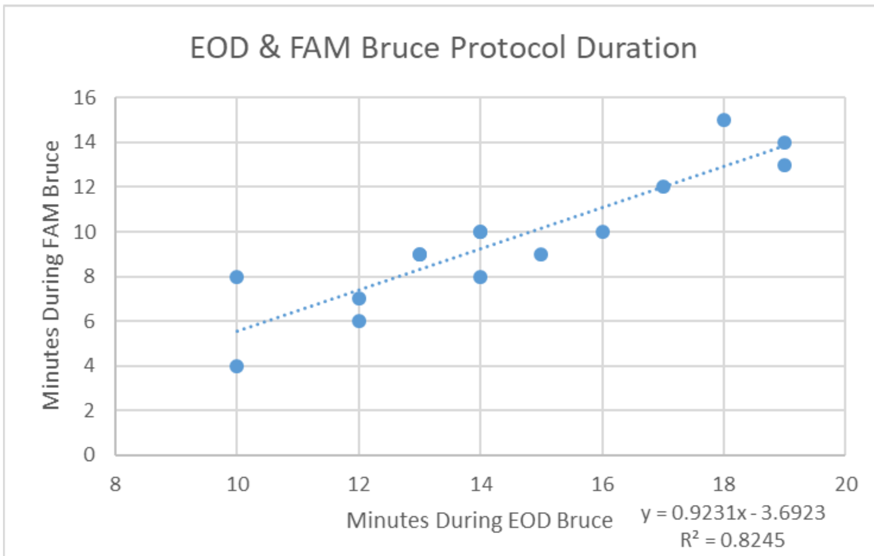

Figure 15: Correlation between subjects' FAM and EOD Bruce progressions

Figure 15 shows a strong significant positive correlation (R=.91) (P<0.01) between the amount of time subjects could progress through the Bruce protocol with and without the EOD suit. The data suggests that subjects who could progress farther through the FAM Bruce protocol could also progress farther through the EOD Bruce protocol.

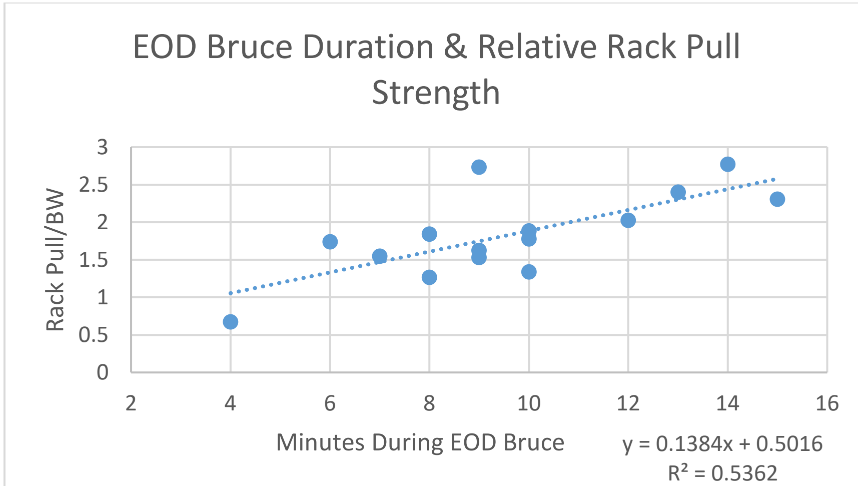

Figure 16: EOD Bruce Duration & Relative Rack Pull Strength

Figure 16 shows a significant and positive relationship (R=.73) ($P<0.01$) between the time subjects could progress through the EOD Bruce protocol and their rack pull strength divided by their body weight. The data suggest that as subjects become stronger relative to their body weight, their ability to progress through the Bruce protocol while loaded with the EOD suit improves.

Table 9: Correlation table for measures of strength, power, endurance, and body composition to EOD duration.

	FAM Rack Pull	Rack Pull relative to BW	FAM Sled Pull	FAM Stair Sprint	FAM Duration	Body Fat %	FAM VO2 max
Correlation (R) with EOD Duration	0.605**	0.732**	-0.614**	-0.628**	0.908**	-0.752**	0.777**

**Significant at P<0.01

V: Discussion

Summary

The results clearly indicate a large difference between the familiarization performance and the EOD performance. This replicates previous findings (Bach et al., 2017, Wu et al., 2022), with added findings concerning the relationship between strength, power, and endurance with a change in the increased demand brought on by EOD load carriage. RPE and HR are dramatically increased by load carriage through the stages in a parallel manner, as displayed by figures 1 and 2. The VO2 needed to continue the Bruce protocol is also increased, with a steeper incline as the Bruce protocol progresses. This is likely since individuals reach a maximal effort faster while loaded, it accelerates their increased oxygen need, effectively compressing the graph in comparison to what we'd expect from the unloaded trial. RER increases through the 2nd and 3rd stage, but was not significantly different during stage one. The difference in the second and third stages compared to the FAM condition is likely due to the more anaerobic nature of EOD load carriage. There were significant correlations between stair sprint time and the upregulation in HR, sled pull time and the upregulation of VO2, and VO2 max with upregulation in HR ($P<0.01$).

Only three subjects made it through the most intense stage (stage 3) of the modified Bruce protocol in the EOD suit, and so it seemed prudent to consider how far subjects could progress as a measure of load carriage fitness/readiness. Some of the strongest correlations from the study came from correlating the amount of minutes subjects were able to progress during the EOD Bruce protocol with the measured markers of performance and body composition. Figures 10-16 display these correlations, the strongest of which was Bruce treadmill duration with and without the EOD suit.

Metabolic Testing

VO2 Demands

The EOD gear had significantly greater VO2 demands at all stages than the FAM trial. This means that EOD personnel operate much closer to their aerobic maximum than they would without their PPE. This finding is consistent with/surpasses previous findings (Boffey et al., 2019, Krajewski 2014), in that the subjects did not reach a steady state per stage of the Bruce protocol, though the stages utilized in the referenced studies were much longer. In terms of percentages of maximum aerobic capacity, one study found that a 35 kg rucksack carried at 3 km/h caused subjects to work at 26±3% (Godhe et al., 2020) of their VO2 max, and the present study found that subjects worked on average at 35±.13% of their VO2 max. This was at a similar but slightly lower speed (2.7km/h), so the current study found greater demand than previous rucksack studies, at a lower intensity.

Rate of Perceived Exertion

The subjects rated the EOD gear as being significantly harder through all stages, to the degree that subjects rated stage three as being 40% harder than without the EOD gear, which is greater than previously found in studies utilizing rucksacks (Beekley et al., 2007). The RPE was also rated higher than was found in a study utilizing a firefighting modality, such that subjects rated the EOD suit as 20% more difficult (Abel et al., 2011).

This may have significant impact on the psychological mettle necessary to perform EOD operations, and is likely a result of the decreased ability to thermoregulate due to the suit's insulative nature and additional weight, which in turn increases the demand placed on the body, resulting in increased discomfort and exertion.

Respiratory Exchange Ratio

The increased RER indicates that when wearing the EOD suit, the wearer relies on more glycolytic energy sources for the same amount of work. For future application, this may inform on the optimized diet to be made available to EOD personnel. Subjects also surpassed 1.00 an average of three minutes (the duration of one stage) sooner during the EOD trials than they did during the FAM trials. This indicates that subjects began working anaerobically and glycolytically much sooner, which means they were heavily utilizing carbohydrates as a fuel source over fats, and were much more uncomfortable while doing so. These findings are in contrast with previous findings (Krajewski 2014), as the present subjects did not reach a steady state, and RER continued to increase even within stages. The RER demand found in the present study also surpassed that of another study (Beekley et al., 2007), which yielded an average of .93 RER, despite loads weighing 70% of the wearer's lean body mass. This supports the premise that the EOD gear brings on higher demand for more reasons than its weight alone.

Correlations

Metabolic Demand

There were several significant correlations between measures of fitness and the change in metabolic demand, at both the $P<0.05$ and $P<0.01$ level, as shown in Table 8. The strongest of these correlations was between VO2 max (as measured by Bruce treadmill protocol) and the change in HR throughout the Bruce protocol ($R=.727$), followed by the stair sprint and the change in HR ($R=-.683$), followed more closely by sled pull time and change in VO2 ($R=-.606$). These three correlations were significant, ($P<0.01$), and they may imply that as an individual becomes more powerful (as measured by stair sprint and sled pull), they are able to upregulate more in terms of VO2 and HR to accommodate for the increased demand, effectively increasing performance.

Bruce Protocol Duration

As shown in Table 9, FAM measures of rack pull, rack pull relative to body weight, sled pull, stair sprint, body fat percentage, and VO2 max were all significantly correlated ($P<0.01$) to the amount of time the subjects could walk through the Bruce protocol while wearing the EOD suit. At $R=.908$, the strongest correlation was between the duration subjects were able to walk through the Bruce protocol with and without the EOD suit. The next strongest correlated were BF% ($R=-.75$), VO2 max ($R=.77$), and relative rack pull ($R=.73$), which are findings consistent with previous literature concerning lean vs fat mass, aerobic fitness, and relative strength (Godhe et al., 2020, Knapick et al., 2004, Robinson et al., 2018).

Overall Significance

The present study has found significant correlations between measures of fitness and both load carriage endurance and increased upregulation with the addition of the EOD suit. Stronger relationships were found between measures of endurance (VO2 max) and relative strength (rack pull relative to BW) and higher EOD load carriage performance, but significant correlations were also found for measures of power (stair sprint, sled pull), and to a lesser degree, raw strength (isometric rack pull). This implies that aerobic fitness and relative strength are the most correlated fitness markers to EOD load carriage performance, but that being more powerful may also improve field readiness. Between the two measures of power (sled pull and stair sprint), stair sprint time (sec) was more strongly correlated to the increased upregulation in HR and VO2 between the EOD and FAM Bruce protocol and longer durations of the EOD Bruce protocol. While this may be a product of the fact that most subjects had ran up a flight of stairs but had never pulled a weighted sled (task familiarity), it may also be that measures of body-weight based exercises may be a better judge of EOD load carriage efficiency. This is further supported by the stronger relationships discovered between relative strength and performance, which were stronger than relationships concerning power. This is an area that requires future study, as the difference between sled pull and stair sprint was statistically insignificant ($P>0.05$). The use of Bruce duration as a measure of EOD load carriage performance was one unutilized until the present study. This measure seems like an appropriate one for future studies because of its relevance to field duties; EOD operators need to get to and from their destination, and the amount of time/distance they are able to traverse is paramount to timely success. Further, the strongest correlations in this study were in relation to the Bruce protocol duration, potentially indicating that the fitness tests may be more accurate predictors of field performance, but this is a conclusion that cannot be drawn from this study alone, and is an area that requires further study.

Limitations

A limitation in this study was access to adequately trained individuals. Several subjects did not make it into the third stage of the Bruce protocol while in the EOD suit, so data capture was limited to the portion of the protocol they could complete. Further, subjects had no experience with EOD load carriage, and therefore were not accustomed to the EOD suit. Another limitation includes potential fluctuations in the performance of female subjects depending on their menstrual cycle. These fluctuations in performance are likely not significant enough to heave great impact on this study's data, given the large effect size granted by the EOD intervention (Julian et al., 2017) (See Table 10). Lastly, the researchers could not control for psychological readiness, which likely plays some role in an individual's ability to maintain their effort through the Bruce treadmill protocol.

Table 10: The menstrual cycle's effect on performance

Variables	FP	LP	P
0-5m (s)	1.1±0.1	1.1±0.1	1.00
0-10m (s)	1.9±0.1	1.9±0.1	0.25
0-30m (s)	4.7±0.1	4.7±0.1	0.96
CMJ	29.0±3.9	29.6±3.0	0.33
IET (M)	3289±801	2822±896	0.07

FP= Early Follicular Phase; LP= Mid luteal Phase; CMJ= counter movement jump; IET= intermittent endurance test
Adapted from: Julian, R., Hecksteden, A., Fullagar, H. H., & Meyer, T. (2017). The effects of menstrual cycle phase on physical performance in female soccer players. PloS one, 12(3), e0173951.

Future Directions

Psychological readiness may be a source of interest for future studies, especially if paired with a possible learning effect, which is another worthwhile area for future study. The crossover effect physiological demands have on cognitive demands should also be studied further, as decision-making skills need to remain as unhindered as possible during EOD operations. To more closely simulate EOD field operations, it may be worthwhile to conduct a time trial testing measure, similar to the work done by Wu et al., 2022. This would be especially useful if paired with thermal stress measurements, because thermic stress is likely a strong contributing factor to the increased demand brought on by the EOD gear. Additionally, a longitudinal study following different groups through different training programs and their consequent load carriage performance, similar to research performed with law enforcement (Robinson et al., 2018), may provide the most clarity about which training programs provide the most readiness.

References

Abel, M. G., Mortara, A. J., & Pettitt, R. W. (2011). Evaluation of circuit-training intensity for firefighters. The Journal of Strength & Conditioning Research, 25(10), 2895-2901.

Bach, A. J., Costello, J. T., Borg, D. N., & Stewart, I. B. (2017). The Pandolf load carriage equation is a poor predictor of metabolic rate while wearing explosive ordnance disposal protective clothing. Ergonomics, 60(3), 430-438.

Bastien GJ , Willems PA, Schepens B, Heglund NC. (2005). Effect of load and speed on the energetic cost of human walking. Eur J Appl Physiol; 94(1): 76–83.

Beekley, M. D., Alt, J., Buckley, C. M., & Duffey, M. (2007). Effects of heavy load carriage during constant-speed, simulated, road marching. Military medicine, 172(6), 592-595.

Billing, D. C., Silk, A. J., Tofari, P. J., & Hunt, A. P. (2015). Effects of military load carriage on susceptibility to enemy fire during tactical combat movements. The Journal of Strength & Conditioning Research, 29, S134-S138.

Blacker SD , Fallowfield JL, Bilzon JLJ, Willems MET. (2003). Physiological responses to load carriage during level and downhill treadmill walking. Med Sport; 13(2): 108–24.

Boffey, D., Harat, I., Gepner, Y., Frosti, C. L., Funk, S., & Hoffman, J. R. (2019). The physiology and biomechanics of load carriage performance. Military Medicine, 184(1), E83-E90. doi:https://doi.org/10.1093/milmed/usy218

Brown PI , McConnell AK. (2012). Respiratory-related limitations in physically demanding occupations. Aviat Space Environ Med; 83(4): 424–30.

Cheung, S. S., Petersen, S. R., & McLellan, T. M. (2010). Physiological strain and countermeasures with firefighting. Scandinavian journal of medicine & science in sports, 20 Suppl 3, 103–116. Link.

Christie, C. J., & Scott, P. A. (2005). Metabolic responses of South African soldiers during simulated marching with 16 combinations of speed and backpack load. Military medicine, 170(7), 619-622.

Dempsey PC, Handcock PJ, Rehrer NJ. (2013). Impact of police body armour and equipment on mobility. Appl Ergon;44(6):957–61.

Drain JR , Aisbett B, Lewis M, Billing DC. (2017). The Pandolf equation under-predicts the metabolic rate of contemporary military load carriage. J Sci Med Sport; 20: S104–8.

Drain, J., Billing, D., Neesham-Smith, D., & Aisbett, B. (2016). Predicting physiological capacity of human load carriage–A review. *Applied Ergonomics*, *52*, 85-94.

Grant, J. A., Joseph, A. N., & Campagna, P. D. (1999). The prediction of VO2max: a comparison of 7 indirect tests of aerobic power. The Journal of Strength & Conditioning Research, 13(4), 346-352.

Foster, C., Farland, C. V., Guidotti, F., Harbin, M., Roberts, B., Schuette, J., Tuuri, A., Doberstein, S. T., & Porcari, J. P. (2015). The Effects of High Intensity Interval Training vs Steady State Training on Aerobic and Anaerobic Capacity. Journal of sports science & medicine, 14(4), 747–755.

Godhe, Manne, MSc, Helge, Torbjörn, MSc, Mattsson, Mikael, PhD, Ekblom Örjan, Ekblom, Björn. (2020) Physiological Factors of Importance for Load Carriage in Experienced and Inexperienced Men and Women, Military Medicine, Volume 185, Issue 7-8, Pages e1168–e1174, Link.

Harman, E. A., Rosenstein, M. T., Frykman, P. N., Rosenstein, R. M., & Kraemer, W. J. (1991). Estimation of human power output from vertical jump. The Journal of Strength & Conditioning Research, 5(3), 116-120.

Julian, R., Hecksteden, A., Fullagar, H. H., & Meyer, T. (2017). The effects of menstrual cycle phase on physical performance in female soccer players. *PloS one*, *12*(3), e0173951.

Keren, G., Magazanik, A. & Epstein, Y. A comparison of various methods for the determination of VO2max. Europ. J. Appl. Physiol. 45, 117–124 (1980). Link.

Knapik, J. J., Reynolds, K. L., & Harman, E. (2004). Soldier load carriage: historical, physiological, biomechanical, and medical aspects. Military medicine, 169(1), 45-56.

Kobus, D. A., Brown, C. M., Wu, L., Robusto, K., & Bartlett, J. (2010). Cognitive performance and physiological changes under heavy load carriage. PACIFIC SCIENCE AND ENGINEERING GROUP INC SAN DIEGO CA.

Krajewski, S. (2014). Energy cost of heavy load carriage and prolonged walking in ROTC collegiate participants (Order No. 1558823). Available from ProQuest Dissertations & Theses Global. (1553447833). Retrieved from Link.

Kusumoto, H., Ta, C., Brown, S. M., & Mulcahey, M. K. (2021). Factors contributing to diurnal variation in athletic performance and methods to reduce within-day performance variation: a systematic review. *The Journal of Strength & Conditioning Research*, *35*, S119-S135.

Majumdar D , Srivastava KK, Purkayastha SS, Pichan G, Selvamurthy W. (1997). Physiological effects of wearing heavy body armour on male soldiers. Int J Ind Ergon; 20(2): 155–61.

Mala, J., Szivak, T. K., Flanagan, S. D., Comstock, B. A., Laferrier, J. Z., Maresh, C. M., & Kraemer, W. J. (2015). The role of strength and power during performance of high intensity military tasks under heavy load carriage. US Army Medical Department Journal.

Mala J, Szivak TK, Kraemer WJ. (2015) Improving performance of heavy load carriage during high-intensity combat-related tasks. Strength and Conditioning Journal;37(1):43–52.

Mann, J. Bryan1,2; Ivey, Pat J.1; Brechue, William F.3; Mayhew, Jerry L.3,4. Validity and Reliability of Hand and Electronic Timing for 40-yd Sprint in College Football Players. Journal of Strength and Conditioning Research: June 2015 - Volume 29 - Issue 6 - pg 1509-1514

Marins, Cabistany, Bartel, Dawes, & Del Vecchio. (2020). Effects of Personal Protective Equipment on the Performance of Federal Highway Policemen in Physical Fitness Tests. Journal of Strength and Conditioning Research, 34 (1), 11-19. doi: 10.1519/JSC.0000000000003201.

Martin PE, Nelson RC. (1986). The effect of carried loads on the combative movement performance of men and women. Mil Med 150: 357–362.

Morrissey MC, Harman EA, Johnson MJ. (1995). Resistance training modes: specificity and effectiveness. Medicine and Science in Sports and Exercise. May, 27 (5):648-660. PMID: 7674868.

Pimental, Nancy & Pandolf, Kent. (1979). Energy expenditure while standing or walking slowly uphill or downhill with loads, Ergonomics, 22:8, 963-973, DOI: Link.

Robinson, J., Roberts, A., Irving, S., & Orr, R. (2018). Aerobic Fitness is of Greater Importance than Strength and Power in the Load Carriage Performance of Specialist Police. International journal of exercise science, 11(4), 987–998.

Seay, J. F. (2015). Biomechanics of load carriage—Historical perspectives and recent insights. The Journal of Strength & Conditioning Research, 29, S129-S133.

Sleivert, G., & Taingahue, M. (2004). The relationship between maximal jump-squat power and sprint acceleration in athletes. European journal of applied physiology, 91, 46-52.

Sol, J. A., Ruby, B. C., Gaskill, S. E., Dumke, C. L., & Domitrovich, J. W. (2018). Metabolic demand of hiking in wildland firefighting. Wilderness & Environmental Medicine, 29(3), 304-314.

Spudić, D., Cvitkovič, R., & Šarabon, N. (2021). Assessment and Evaluation of Force–Velocity Variables in Flywheel Squats: Validity and Reliability of Force Plates, a Linear Encoder Sensor, and a Rotary Encoder Sensor. Applied Sciences, 11(22), 10541.

Taylor, N. A., Peoples, G. E., & Petersen, S. R. (2016). Load carriage, human performance, and employment standards. Applied physiology, nutrition, and metabolism, 41(6), S131-S147.

Tholl, U., Forstner, K., & Anlauf, M. (2004). Measuring blood pressure: Pitfalls and recommendations. Nephrology Dialysis Transplantation, 19(4), 766-770.

Wu, Y. N., Norton, A., Zielinski, M. R., Kao, P. C., Stanwicks, A., Pang, P., ... & Yanco, H. A. (2022). Characterizing the Effects of Explosive Ordnance Disposal Operations on the Human Body While Wearing Heavy Personal Protective Equipment. Human Factors, 64(7), 1137-1153.