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Effect of Body Mass and Added Mass on Treadmill Performance

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by

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ABSTRACT

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Strenuous physical activity in extreme environments is an important part of the activities of military personnel. The average infantry combat load for an infantry soldier in Afghanistan is about 30 kg, but can be as much as 58 kg (Dean & DuPont, 2008). Studies demonstrate that there is a significant decrease in the ability of individuals to perform aerobic work when carrying a heavy load (Christie & Scott, 2005; Beekley et al., 2007; Quesada et al., 2000). There has been little research done on the correlation between performance on load carriage activities and the non-load carriage activities traditionally used as indicators of aerobic performance in the military. This study evaluated the role of body mass and of added mass on aerobic performance by comparing individuals with differing body mass on uphill treadmill tests of varying loads, specifically, 0 kg, 10 kg, 20 kg and 30 kg. The study also assessed the relationship of performance on a traditional unloaded run test, the 4.8-km run, with performance on the loaded tasks. Subjects performed an outdoor 4.8-km run and four maximal treadmill tests wearing the loads listed above. Subjects' pulmonary function was tested with load prior to each treadmill session. Peak values of heart rate, VO_2, exercise ventilation, and respiratory exchange ratio were measured at the end of each maximal treadmill test. Significant decreases were found in pulmonary function measures (FEV_1, FVC and MVV) with increasing load. Most peak responses during treadmill exercise, VO_{2peak}, HR_{peak}, and V_{Epeak}, decreased with increasing load. However, RER_{peak} did not decrease,

which was unexpected. More research is needed to explain the lack of decrease in RER_{peak}. The ratio of V_{Epeak} to MVV remained constant with increasing load, suggesting that the decreased performance with load was due to a limitation in breathing capacity. There was not a strong correlation between body mass or lean body mass and performance on the loaded treadmill tasks. The only exception to this was that males showed significant correlation between body mass and performance on the 30-kg trial. More research needs to be done with a group of subjects of more uniform fitness level to determine if loaded treadmill tests show a more significant correlation with body mass. Also, this study confirmed that an unloaded distance run is strongly related to unloaded uphill treadmill performance, but is more poorly related as load is increased on the treadmill test, suggesting that traditional unloaded run tests are not an effective means of evaluating aerobic performance for military field operations.

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INTRODUCTION

Problem Description

Strenuous physical activity in extreme environments is an important part of the activities of military personnel. In combat situations, they must also carry heavy loads including weapons, ammunition, protective equipment (e.g., body armor, helmet, etc.), food, water and survival supplies. The average load for an American infantry soldier in Afghanistan is about 30 kg, but can be as much as 58 kg (Dean & DuPont, 2008). This is significantly more than soldiers were carrying even as recently as the Vietnam and Korean wars (Knapik et al., 2004). The effects of these increasing loads on the aerobic function of soldiers have not been fully studied. Also, it is unclear how soldiers of differing body size and composition may be affected by these heavy loads.

There is a significant decrease in the ability of individuals to perform aerobic work when carrying a heavy load (Christie & Scott, 2005; Beekley et al., 2007; Quesada et al., 2000). However, there has been little research done on the correlation between performance on load carriage activities and the non-load carriage activities traditionally used as indicators of aerobic performance in the military. Researchers have argued that load carriage tests are more occupationally relevant than unloaded run times for military personnel (Vanderburgh, 2008; Vanderburgh & Flanagan, 2000; Bilzon et al., 2001).

It is also important to understand the influence that individual characteristics play on load carriage performance. In particular, there is a link between a person's body mass and his or her performance on aerobic tasks. The correlation appears to work in two directions. Smaller individuals perform better in tasks that assess aerobic ability relative to one's own body mass, such as an unloaded 4.8-km run. This size effect is due to scaling, in which the relationship between certain physical characteristics varies in individuals of different body sizes. In particular, when VO_{2max} is measured in relative terms (i.e., in $mL \cdot min^{-1} \cdot kg^{-1}$), smaller individuals have greater aerobic capacities (Swain, 1994). However, larger individuals may out-perform their smaller counterparts in aerobic tests that require load-carriage, since a load of a given absolute mass would be a smaller percentage of the larger person's mass, and thus an easier challenge for the larger individual to perform (Lyons et al., 2005).

Evidence exists that current physical fitness tests used by the United States military may be unfairly biased toward individuals with a low body mass (Lyons et al., 2005; Vanderburgh & Flanagan, 2000; Vanderburgh, 2008). Current military fitness tests require personnel to engage in activities where only their body weight is moved, such as running, push-ups, pull-ups and sit-ups, which may bias these tests toward smaller individuals. These non-load bearing tests favor smaller individuals due to scaling and, further, may not be occupationally relevant to military activities. Some researchers suggest that load-bearing tests should be used to achieve higher occupational relevance (Bilzon et al., 2001). On the other hand, tests in which a soldier has to move significant extra loads may actually be biased toward larger individuals (Lyons et al., 2005; Bilzon et al., 2001). Some solutions suggested to remedy this issue are the use of backpack run tests and scaling equations for unloaded tests (Vanderburgh, 2008; Vanderburgh & Flanagan, 2000). However, run tests with backpacks are performed on level terrain, just as the distance run test is currently administered, whereas infantry operations, especially in Afghanistan, often involve carrying loads uphill. An uphill task, such as carrying a load up a treadmill, may be more occupationally relevant for the military.

The details of what physiological characteristics cause differences in load-bearing aerobic performance have not been thoroughly described. Also, some studies have investigated whether the difference is linked to body mass (BM) or if it might actually be more associated with lean body mass (LBM) (Beekley et al., 2007; Lyons et al., 2005). The goal of this study was to help fully understand the effects of load carriage on the aerobic performance of individuals and the correlation to unloaded run time, BM and LBM. The results will also help in the design of future studies to determine the most occupationally relevant fitness tests to be used with military personnel.

Statement of Purpose

The purpose of this study was to evaluate the role of body mass and of added mass on aerobic performance by comparing individuals with differing body mass on the 4.8-km run test and on uphill treadmill tests of varying loads, specifically, 0 kg, 10 kg, 20 kg and 30 kg.

Hypotheses

1. There will be a significant decrease in performance, as measured by treadmill time, with increasing amounts of load carried by the subject.
2. There will be a significant correlation of unloaded treadmill performance with 4.8-km run performance, but this correlation will decline as load on the treadmill task increases.
3. There will be a significant difference between the performance of subjects with large and small BM in the 4.8-km run test and the treadmill tests.
   a. Subjects with a large BM will perform better on the treadmill tests with high loads.

b. Subjects with a small BM will perform better on the 4.8-km run test and the treadmill test with no load.

c. The optimum BM (associated with the best performance) will increase with increasing load on the treadmill tests.

4. There will be a significant difference between the performance of subjects with large and small LBM in the 4.8-km run test and the treadmill tests.

   a. Subjects with a large LBM will perform better on the treadmill tests with high loads.

   b. Subjects with a small LBM will perform better on the 4.8-km run test and the unloaded treadmill test.

   c. The optimum LBM (the LBM associated with the best performance) will increase with increasing load on the treadmill tests.

5. With increasing load, there will be a decrease in the pulmonary measures of forced vital capacity (FVC), and maximal voluntary ventilation (MVV) due to a decreased ability to inflate the lungs. There will also be a decrease in peak exercise ventilation ($V_{E\,peak}$) with increasing load for the same reason.

6. With increasing load there will be a decrease in the pulmonary function measure of forced expiratory volume in 1 second (FEV_1) due to a decreased FVC. Given a decrease in both FVC and FEV_1, the ratio of FEV_1 to FVC will remain the same with increasing load.

7. With increasing load, there will be a decrease in VO_{2peak} due to musculoskeletal and ventilation limitations. Peak values for the respiratory exchange ratio (RER) will also decrease with increasing load because of these limitations.

Limitations

One limitation was that not all the recruited subjects were military personnel. Therefore, not all subjects had experienced the type of training that is used in the military. A different relationship might be observed if the study were repeated exclusively with military personnel. Another limitation was that all subjects were required to be highly active. This means that the results of this study will not apply to the general population, especially sedentary individuals. Since all subjects were adults between the ages of 18 and 44 years, results also cannot be generalized to children or older adults. Finally, results of this investigation would likely have been more significant if there were a wider range of body masses and a narrower range of fitness levels among subjects recruited for the study.

Operational Definitions

- VO_{2max}: The highest oxygen consumption measured over a continuous 60-sec period during exercise, provided the RER is at least 1.10 or provided that a plateau in oxygen consumption is reached (increase in VO_2 from one completed stage to the next completed stage is less than half of the expected increase).
- VO_{2peak}: The highest oxygen consumption measured over a continuous 60-sec period during exercise, even though RER may be less than 1.10 and no plateau in VO_2 is observed. Given the expectation that incremental tests performed with load in this study might not reach true maximal levels of aerobic metabolism, VO_{2peak} is used in this study.
- Respiratory Exchange Ratio (RER): The ratio of carbon dioxide production to oxygen consumption.

- Highly active: Recent national guidelines have recommended that adults obtain at least 2.5 hours of moderate intensity physical activity per week, or at least 1.25 hours of vigorous intensity physical activity per week, and further recommended that twice this level of activity is better (USDHHS, 2008). For the purposes of this study, highly active is defined as having obtained at least 2.5 hours of vigorous intensity physical activity per week over the 4 weeks prior to the start of testing.
- Metabolic units (METs): A metabolic unit is the value of VO_2 necessary to maintain vital body function at rest. This is defined as 3.5 $mL \cdot min^{-1} \cdot kg^{-1}$.
- Moderate intensity physical activity: Physical activity with an oxygen consumption of 3-5.9 times that at rest, or 3-5.9 metabolic units (METs). This could include walking, ballroom dancing and slow road bicycling (USDHHS, 2008).
- Vigorous intensity physical activity: Physical activity with an oxygen consumption of 6 or more times that at rest, ($\geq$ 6 METs). This could include running, swimming laps, hiking uphill, competitive sports (tennis, soccer, basketball) and heavy weight training (lifting to failure in multiple sets with a brief rest period) (USDHHS, 2008).
- Lean Body Mass (LBM): The mass of the lean portions of the body as estimated by taking the body mass and subtracting the fat mass. For this study, the fat mass will be estimated using air plethysmography.

CHAPTER II

LITERATURE REVIEW

Effects of Load Carriage on Aerobic Performance

In order to understand how increasing load affects treadmill performance, it is important to first investigate what research has been done on the effect of load on aerobic performance. Some research has directly measured the effect of load carriage on specific physiological indicators, while others simply studied performance on an aerobic task while carrying a weight. Most studies used the method of the backpack or some variation of this since this seems to be the most efficient method of load carriage when measured by energy cost (Legg et al., 1992). A 2004 review article by Knapik et al. attempted to provide a comprehensive look at soldier load carriage, expanding on historical, physiological, biomechanical and medical perspectives. The authors pointed out that it is not unusual for the modern soldier to carry more than 50 kg. This amount may continue to increase as combat equipment becomes even more sophisticated and advanced. In the physiological analysis of load carriage, Knapik et al. explain that, in addition to contributions from grade and terrain, both body weight and the amount of load carried increase the amount of energy cost for walking (Knapik et al., 2004). This general concept has been verified in research studies, which found that the volume of oxygen consumed increased with increasing load mass (Keren et al, 1981; Beekley et al., 2007; Pal et al., 2009).

Many exercise scientists have studied the energy cost of running, walking and other aerobic tasks. However, recent research has also begun to look at the impact that load carriage has on energy cost to help describe the aerobic intensity required of military personnel and those in other occupations that require significant load carriage, such as firefighting. An early study of this type was performed by a group of Israeli researchers in 1981 (Keren et al.). Fifteen healthy and active male college students performed two treadmill walking/running tests at 5% incline. They walked at increasing speeds until they were asked to run at 9.6 kph (6 mph). They undertook this protocol both unloaded and with a 20-kg load. By measuring the VO_2 of the subjects, the researchers were able to develop regression lines for the energy cost related to speed for walking and running with and without load. As expected, energy cost was higher with a load than without a load at every speed.

Another finding of the Keren et al. study (1981) was that the intersection point of the walking and running energy cost lines occurred at a lower speed with the load than without load. The lower walking and running energy cost intersection indicates that running may be a more efficient mode of transportation with a load than unloaded. A later study performed in Massachussetts confirmed this decrease in the transition point between walking and running with increasing load (Epstein et al., 1987). The Keren study also found that the transition point differed with the mass of the subjects. The weighted and unweighted transition point for the five largest subjects stayed the same. However, when the five smallest subjects performed the weighted protocol, their transition point occurred at a much lower speed than without the weight. Findings similar to the Keren study may indicate that higher BM individuals may perform better when carrying a load because of a lower energy cost.

A study done by the military at the University of Health Sciences in 2008 measured the energy cost of activities with and without body armor using the rating of perceived exertion as well as blood lactate levels, heart rate, VO_2 and RPE (Ricciardi et al.). Subjects performed treadmill testing at slow and moderate paces and were assessed in hand grip strength, stair stepping and pull-ups or hang time. Tests were done with and without wearing body armor. VO_2, heart rate, respiratory rate and RPE all increased with the addition of body armor for both the slow and moderate paced walking treadmill test. In the other physical fitness tests, only pull-ups were significantly decreased by wearing body armor. This one and the previous studies show the significant increase in energy cost that comes with increased load, demonstrating the need for metabolic training to prepare soldiers for this part of their occupation.

A study done by Quesada et al. (2000) found an increase in V_E when carrying a backpack load. The increased ventilation was due to the increased energy cost of carrying the load. Stuempfle et al. (2004) also found that V_E levels increased with a low load position as compared to a position higher on the back. Therefore, participants would be expected to fatigue earlier when carrying a heavier load.

The Quesada et al. study investigated the effects of three different loads on VO_2, HR and RER. The study required U.S. army recruits to perform 40 minute marches while carrying no load, 15% BM and 30% BM loads in a typical army backpack. The researchers found significant increases in VO_2 and HR with increasing load. This indicates that the subjects were experiencing a significant increase in energy cost. However, an unusual finding was that RER levels were not significantly different between the three different loads, suggesting that substrate utilization was similar for all three conditions. A study by Stuempfle et al. (2004) also measured VO_2, HR and RER, but looked for effects of load position rather than mass. This study found that VO_2

increased with the low load compared to the high load position. HR and RER showed no significant increase. This study indicated that carrying a load low on the back also increases energy cost when compared to a high load position.

A study performed by Sagiv et al. (2000) examined the effects of load carriage on hemodynamic responses to exercise. The researchers recruited a group of endurance trained athletes to participate in 4 separate sessions. In the first session, the Bruce protocol for $VO_{2\ max}$ testing was followed. In the next 3 sessions, the subjects participated in 45-minute treadmill walks carrying 0, 25 and 35 kg in a backpack. These walks began at 0% grade and were increased by 5% every 15 minutes. Researchers measured VO_2, blood pressure and the aortic blood flow before, during and after exercise. They found that although there were significant increases in all measures from 0 kg for both loads, there was not a significant increase from the 25 to 35 kg loads (Sagiv et al., 2000). These results may indicate a greater effect of gradient on metabolic processes, or it may indicate that the 10 kg difference was not enough to be statistically detected in these highly trained athletes.

Some studies have tried to link these physiological effects to practical situations that would be faced by a soldier in a combat or training situation. Christie and Scott (2005) performed a study with a group of South African soldiers in which they observed the ability of these soldiers to perform walking tasks at varying speeds with differing loads. They used these data to recommend a range of weights and speeds that might be acceptable for use in a combat situation. They also recognized, however, that these ranges may not be appropriate for military from other countries because of the relative short stature and low aerobic fitness of the South African soldiers sampled. Pal et al. (2009), also recommended an optimum range of load weights, this time for Indian infantry soldiers. This range was based on a percentage of the individual's body weight. Their findings were more individualized than the Christie and Scott study. They did not, however, take into account the body composition of the subjects.

Some studies have drawn correlations between the physiological effects of load carriage and body composition. Beekley et al. (2007) found that very heavy loads may not be tolerated physiologically by individuals that are very short or who have a higher than average body fat percentage. Lyons et al. (2005) also found that absolute $VO_{2\,max}$ levels (expressed in $L \cdot min^{-1}$) were very closely related to the subjects' lean body mass to dead mass (fat mass + load mass) ratio (2005). These studies suggest that body composition may play a key role in the ability to tolerate load carriage. This idea will be explored more in later sections of this thesis.

Effects of Load Carriage on Pulmonary Function

An early study by Muza et al. (1989) suggested that load decreases FVC and FEV_1 with no change in FEV_1/FVC. A decrease in MVV was found between no load and a10kg load, but not between a 10kg and 30kg load. A similar study by Legg (1988) showed a decrease in FVC with the addition of light body armor (<10kg). Like Muza et al., Legg found no significant change in FEV_1/FVC. The phenomenon of reduced FVC and FEV_1 with no change in ratio is characteristic of restrictive respiratory disease. Therefore, the addition of load can be considered to have the effect of a mild restrictive respiratory disease (Muza et al., 1989). An example of a condition causing respiratory restriction would be obesity. A study by Wang and Cerny (2004) simulated obesity using chest loading and found a reduction in baseline FVC and FEV_1.

The findings of Muza et al. and Legg's early studies are further confirmed by later research. In 2005, Chow and colleagues investigated the effects of backpack carriage on pulmonary function of schoolgirls. This study found significant decreases in FVC and FEV_1 with increasing mass of the backpack load, but no difference in FEV1/FVC ratio or peak flow values. Legg and Cruz (2004) found that both double and single-strap backpacks weighing 6 kg decreased FVC values in college students. However, there were no significant changes in FEV_1 or FEV_1/FVC.

Bygrave et al. (2004) investigated the effects of a 15-kg backpack on pulmonary function. This study, using 12 healthy male participants, found a significant decrease in FVC and FEV_1 with the addition of the backpack. They also tested a loose verses a tight fit and found that a tight fitting backpack further decreased FVC and FEV_1. They found no significant changes in the FEV_1/FVC ratio, which is consistent with the aforementioned studies by Chow et al. and Legg and Cruz.

Load Carriage Performance and Run Times

Every branch of the U.S. military includes a distance run in its physical fitness test (Vanderburgh & Crowder, 2006). As military personnel are required to carry increasingly larger loads, it is important to consider whether the unloaded distance run is predictive of performance in load-bearing activities that may be encountered in combat. Two studies, one by Harman et al. in 2008 and another by Pandorf et al. in 2002, found significant correlations between the distance run performance and performance on activities including load carriage. The Harman study found that 3.2-km run performance was a significant predictor of performance in a 400-m run (correlation = 0.68), 30-m rushes (correlation = 0.53) and a timed obstacle course (correlation = 0.57), all completed while wearing 18-kg protective gear. However, this study was done using civilian male subjects, some of whom were significantly deconditioned. Therefore, it is not apparent whether the same predictive value would be seen if the entire group had been highly conditioned. The study performed by Pandorf et al. used only female subjects and found that VO_{2max} and 3.2-km run time were the strongest predictors of 3.2-km run time when wearing 3 different loads (14, 27 and 41 kg). These studies indicate that distance run times provide a reasonable estimate of loaded aerobic performance.

Some further research, however, has indicated that there may be better indicators. A study by Simpson et al. in 2006 required elite British soldiers to perform a Bruce treadmill test, a 3.2-km backpack run test and a 29-km time trial. In the latter time trial, participants performed speed marching over varied terrain and were tested for time of completion. Both the 3.2-km backpack run and the 29-km time trial were performed wearing a 20-kg backpack. The researchers found a correlation between performance on both loaded tests and test duration on the treadmill. However, it is interesting that they did not find any correlation between loaded test performances and relative VO_{2max} measured during the treadmill test. They noted that these results appear consistent with a study by Harman and Frykman in 1995 that found no correlation between a 3.2-km unloaded run and a similar run with a backpack load. These studies indicate that there may be some other mechanism at work when predicting performance on load carrying activities.

Much research has suggested that the complicating factor when using unloaded run times may be body mass. Researchers have suggested that, considering two individuals of the same fitness but different body mass, the smaller one will have a faster distance run time. Vanderburgh and a group of his associates at the University of Dayton have proposed several methods of adjusting run times to better reflect the fitness of the individual (Crecelius et al., 2008; Vanderburgh & Crowder, 2006; Vanderburgh, 2007; Vanderburgh & Mahar, 1995).

Additional research studies have explored alternative tests to the unloaded run tests that would assess aerobic fitness, but also correlate better to the type of load-bearing exercises that are relevant to combat activities. Vanderburgh and Flanagan (2000) recommended a backpack run test for use in military fitness tests because it appeared to be most correlated to absolute VO_2 max. They claimed that their developed test was a much fairer test than the currently used unloaded run test. Klimek and Klimek (2007) tested a weighted walking test to see if it was an appropriate test of VO_{2max} when compared to accepted walking, running and cycling tests. They found that it was indeed a reliable predictor of aerobic capacity when compared to other tests and recommended its use by individuals whose main mode of exercise is climbing or walking while carrying a significant amount of weight.

Effects of Body Mass on Load Carriage Performance

Through a variety of different studies, a number of researchers have suggested that a significant correlation exists between BM and performance on loaded and unloaded aerobic tests. A higher BM appears to improve performance on loaded tasks while harming performance on unloaded running tasks. Keren et al. (1981) found that the energy cost of carrying a load was much higher for a subgroup of subjects with small BM. Bilzon et al. (2001) also studied the relationship between aerobic performance while carrying a weight and BM and found that heavier subjects were able to run for a longer time on an incremental treadmill test while carrying a load than smaller subjects.

The study cited earlier by Pandorf et al. (2002) also found some interesting correlations related to body size. Although no significant relationship was found at the 14 and 27 kg loads, indicators of body size were all significantly related to performance in the 41 kg load test. Increased BM, height, hip circumference, fat mass and LBM were all significantly related to a lower 3.2-km run time carrying 41 kg. Although this study only involved women, the researchers suggested that these data indicate that larger, more muscular soldiers may be more capable of carrying heavy loads in combat situations.

Similar to the Pandorf study, Harman et al. (2008) not only found a significant correlation between distance run time and loaded aerobic tasks, but also a relationship with BM. This study required the subjects to perform 5 separate tests of aerobic fitness. The first was the 3.2-km unloaded run, followed by a 400-m run, 30-m rushes, a casualty rescue drill and an obstacle course, all with subjects wearing an 18-kg load. The 3.2-km unloaded run was a good predictor of performance on the 400-m run, the 30-m rushes and the obstacle course, but not the casualty rescue drill. The best predictor of the casualty rescue drill was BM, with heavier individuals performing significantly better than lighter subjects. This drill also required the subjects to carry considerably higher weight since they were dragging an 80-kg manikin. The combined results of these two studies may indicate that BM is a more important factor as the amount of weight to be carried increases.

Effects of Body Composition on Load Carriage Performance

Whereas increased BM may be a benefit to soldiers participating in load carriage aerobic tasks, certain studies also examined the relationship of performance LBM. Specifically, LBM is considered the metabolically active mass of the body since it contains the skeletal muscle. Also including the internal organs, the blood and skeletal tissue, the LBM is the part of the body that is responsible for mechanically carrying a load (Beekley et al., 2007). The absolute amount of LBM in an individual is also considered an indicator of his or her absolute strength and muscular power. Therefore, heavier, more muscular individuals tend to perform better on tests of absolute strength and power, while lighter individuals tend to perform better on tests of relative muscular endurance and unloaded aerobic endurance (Crecelius et al., 2008; Vanderburgh & Laubach, 2008).

Lyons et al. (2001) conducted a study in which 28 male volunteers performed three 20-minute treadmill tests at different loads: 0, 20 and 40 kg. The gradient was increased every five minutes from 0% to 3, 6 and 9%. Researchers found that percent body fat significantly increased the energy cost of exercise for the 0-kg and 20-kg loads. They also found that the LBM to dead mass ratio (dead mass = fat mass + backpack load mass) was significantly inversely related to the energy cost for subjects in both the 20-kg and 40-kg tests. The decrease in energy cost shows that having a greater proportion of lean body mass is beneficial when attempting to perform load-carrying aerobic tasks and caused the authors to suggest that LBM, rather than total body mass, is best associated with an increase in load carriage performance.

Bias in Current Military Testing Procedures

Distance runs have long been popular tests of aerobic fitness. They are used because they are easy to administer in almost any setting and can be conducted with a large number of people at one time (Vanderburgh & Mahar, 1995). However, increasing evidence exists that these tests may be biased towards smaller, not just fitter individuals. Vanderburgh and Mahar evaluated 3.2-km run times for a large group of young men and compared the times with their BM and LBM. They found that the 3.2-km run penalized men that were heavier, not only because of fat mass, but also men who were heavier due to LBM. Another study found that, in order to remove bias, 5-km run times must be adjusted for age, body mass and fat mass (Crecelius et al., 2008).

In a 2008 review of existing research, Vanderburgh pointed out that the majority of tests used in the military to assess physical fitness appear to be biased in favor of lighter individuals. Every branch of the U.S. military uses a version of the distance run as an assessment of aerobic fitness. Vanderburgh argues that not only is this biased against heavier individuals, it is also not occupationally relevant to military activities. Soldiers very rarely need to run a distance run on flat ground with no load in combat situations. In addition, there is evidence that larger individuals may perform better on load carriage tasks, as previously discussed. Therefore, Vanderburgh argues that the current physical fitness tests in the military may unfairly promote lighter personnel and penalize heavier personnel that may actually be more fit for the physical demands of combat. In addition, tests of muscular endurance, especially those that use only body weight, tend to favor those with smaller BM, including push-up, pull-up, and sit-up tests.

Two quantitative analyses conducted by Vanderburgh and Crowder (2006, 2007) further illustrate the need to adjust the physical fitness requirements of the military. One study used theoretical scaling of exercise tests to predict the difference between individuals that were identical in fitness but different in BM. This scaling showed that a 90-kg man with an identical fitness to a 60-kg man would score 14-17% lower than the lighter man on a military fitness test. The numbers were similar for a 75-kg woman compared to a 45-kg woman. The second study suggested the use of a simple table of correction factors to eliminate this bias, while still allowing the test to be conducted and assessed in the field.

Many other researchers have recognized the problem of fairness and occupational relevancy that is inherent in the types of fitness tests that are currently used for military personnel and members of other occupations that require heavy lifting (Simpson et al., 2006; Ricciardi et al., 2007; Lyons et al., 2005; Bilzon et al., 2001; Harman et al., 2008). Some researchers have suggested alternative fitness tests that could be used. Vanderburgh & Flanagan (2000) recommended a 3.2-km backpack run test that appeared to eliminate bias in their study. Simpson et al. (2006) used a weighted 29-km time trial, as well as the 2-mile backpack run, in their study as tests of elite British soldiers. Harman et al. (2008) used a 400-m run, an obstacle course, 30-m rushes and a simulated casualty rescue (with an 80-kg mannequin), all while wearing an 18-kg load, in their study as occupationally relevant tests. Perhaps one or a combination of these types of tests could be used as a more fair and relevant form of physical fitness testing for military personnel.

Gender Differences in Load Carriage Capacity

With more women entering the military forces, it is necessary to understand if load carriage capacity differs between males and females. Although women are still not allowed to participate in ground combat units, many women have jobs that involve intense physical activity like Military Police work (Pandorf et al., 2002). Research has shown that female stride length shortens more with load than male stride length. Also, females tend to increase the amount of time both feet are on the ground. Another finding is that men tend to be about 21% faster than women regardless of load. These differences appear to be present even when adjusting for BM and composition (Knapik et al., 2004). In general, however, more research needs to be done on the effects of load carriage in women. Few such studies have been undertaken, partially due to the fact that women are less willing to participate in studies and especially to have their BM measured (Crecelius, 2008).

Three studies reviewed directly measured the effects of load carriage on women. Ricciardi et al. (2007) attempted to describe in detail the differences in load carriage effects between males and females. Male and female subjects walked on a treadmill for 30 minutes with a 5-minute warm-up, a 10-minute slow stage, a 10-minute moderate stage and a 5-minute cool-down, with no load and again while wearing body armor. The subjects' rating of perceived exertion (RPE) was recorded at the end of the 10-min stages. In this study, women and men reported similar RPE values with no load, but women reported a greater increase in RPE while wearing body armor. While statistically significant, the women's RPE increased only by a small amount, and the authors believed that it may be of minimal clinical significance. The study also included a number of other physical performance tests, and no significant difference was found between men and women with and without body armor. It was found that age and percent body fat were much better predictors of variance than gender.

A study done by Pandorf et al. (2002) investigated load carriage correlates specifically for women. Women were timed while they completed a 3.2-km run while carrying loads of 14, 27 and 41 kg. They found that the best general predictors of performance were VO_{2max} and unloaded 3.2-km run time. However, when the load was increased to 41 kg, measures of body size also became predictive. Women with the highest BM, height, hip circumference, fat mass and LBM performed better than women with lower measurements when running with the 41-kg load.

A study by Bhambhani and Maikala (2000) investigated gender differences in load carriage at a comfortable walking pace for 4 minutes. In this particular study, the load was held in the hands at chest level in whatever manner was comfortable for the participant. This was done with both a 15-kg and a 20-kg load. The researchers found that women supported less of the weight with their hands than men, resting the load against their bodies. They also found that women were working at a rate above their ventilatory threshold when carrying the 20-kg load. Men generally did not reach this threshold at this level of exercise. The researchers suggested that women will be at a higher risk of cardiovascular complications during load carriage than men.

Overall, studies suggest that load affects women similarly to men, but women most likely have an impaired carrying capacity when compared with similarly-sized male soldiers. Also, the Pandorf et al. study appears to clearly indicate that larger body size is associated with better performance when carrying large loads, such as 41 kg. More research is needed in the area of load carriage in female soldiers in order to fully understand the relevance of these findings.

CHAPTER III

METHODOLOGY

Subjects

Subjects were healthy males and females, ages 18 to 44 years, who were considered low risk by American College of Sports Medicine guidelines (ACSM, 2010). Risk category was assessed using the screening questionnaire attached in Appendix I. The subjects were recruited from the Old Dominion University student body and local military bases. Subjects selected for this study were required to be highly active individuals, defined as individuals engaging in 2.5 hours of vigorous physical activity per week over the past 4 weeks (USDHHS, 2008).

Subjects also were required to be able to perform a screening test carrying a 30-kg load up a flight of stairs without use of the handrails in less than 30 seconds to demonstrate that they were capable of engaging in the activities required for this study. It was necessary to select only active individuals for this study because correlations were drawn between BM and performance. It was assumed that highly active individuals were also highly fit. Observing results for only highly fit individuals would insure that differences in performance were associated with BM, without large variations in fitness levels of individuals acting as a confounding variable.

Procedures

Screening and Anthropometric Measures

Each subject came to the Human Performance Laboratory at Old Dominion University on five separate occasions for an hour each time within a period of one to two weeks. On the first visit, the screening questionnaire was completed by the subject with assistance from the researcher. This questionnaire was used to determine eligibility for the study. Procedures and risks of the study were explained, and written informed consent obtained (Appendix II). The study was approved by the university's Institutional Review Board.

On the first visit, the screening test of stair climbing was performed, and those individuals passing it continued with testing. All participants but one that arrived for the first session passed the screening activity and questionnaire. The one subject that did not pass had the metabolic condition, type 1 diabetes, which places an individual at high risk by ACSM criteria. Three body measures were taken: height, BM, and body composition. Height and BM were measured with the subject wearing shorts and a t-shirt and standing on a balance scale. These measurements were also used to calculate the body mass index (BMI) of the individual. Body composition was measured using the air-displacement plethysmography method (BodPod, Life Measurement, Concord, CA). In order for this technique to be used accurately, subjects were measured wearing skin-tight clothing, such as biking shorts or a skin-tight bathing suit, and a swim cap over the hair.

Load

At each treadmill session, the subjects wore a different load. During one visit, subjects performed the task wearing no load. Another visit, a 10-kg weighted vest was worn. This vest was designed for exercise and research, but was intended to simulate body armor. The vest was adjusted using side straps to ensure a snug but comfortable fit. On the other two visits, subjects wore a two-strap backpack of either 10 or 20 kg, in addition to the weighted vest. The resulting 4 loads were 0, 10, 20 and 30 kg.

Lung function testing

Lung function was tested on each of the four visits involving treadmill testing wearing the specific load to be carried that day (0, 10, 20, or 30 kg), using a metabolic cart (Vmax 29c, SensorMedics, Yorba Linda, CA) to collect expired gases. The flowmeter of the metabolic cart was calibrated against a 3-L syringe prior to each test. While wearing a mouthpiece and a nose clip, subjects were asked to breathe in as deeply as possible and then exhale quickly and fully into the mouthpiece in order to measure FEV_1 and FVC. They then breathed as deeply and quickly as possible for fifteen seconds to measure MVV. The lung function test was conducted with the subject in the standing position.

Testing of Aerobic Performance

Each of the five visits involved one test of aerobic ability. During each test, the subject was fitted with and wore a chest strap heart monitor (Polar, Kempele, Finland) that recorded heart rate throughout the test. On the first visit, the subject engaged in an unloaded 4.8-km run performed along a measured course in the streets outside of the ODU Student Recreation Center (SRC). The subject was instructed to run the distance as fast as possible and was timed. On the next four visits, the subject engaged in maximal incremental treadmill tests in the Human Performance Laboratory (Room 2001, SRC). Each of these tests was performed with varying amounts of additional mass (0 kg, 10 kg, 20 kg, or 30 kg) in a counterbalanced order.

The following stages were used in the incremental treadmill protocol, each lasting three minutes: 4.8 kph (3 mph) and 0% grade, 6.4 kph (4 mph) and 0% grade, 6.4 kph (4 mph) and 5% grade, 6.4 kph (4 mph) and 10% grade, 6.4 kph (4 mph) and 15% grade, 6.4

kph (4 mph) and 20% grade, 7.2 kph (4.5 mph) and 20% grade, 8.0 kph (5 mph) and 20% grade. Subjects were encouraged to continue as long as possible through these stages and stopped when they felt they could no longer continue. During these incremental treadmill tests, the subjects' expired gases were analyzed using the Vmax metabolic cart to determine the rate of oxygen consumption. The O_2 and CO_2 analyzers were calibrated against known gas concentrations prior to each test, and the flowmeter against a 3-L syringe prior to each test. All five visits were completed within a period of 1 to 2 weeks. During this period, subjects were instructed to abstain from other strenuous physical activity within 24 hours prior to each scheduled test.

Statistical Analysis

Anthropometric variables for males and females were compared using a two sample t-test to determine if males and females differed significantly in age, height, BM, body fat percentage, BMI and LBM. Comparison of data collected during the treadmill tests of different loads (VO_{2peak}, RER_{peak}, HR_{peak}, V_{Epeak}, treadmill time) were performed using two-way ANOVA (trials and gender) with repeated measures on one factor (trials). Similarly, pulmonary data (FEV_1, FVC, FEV_1/FVC, MVV) collected prior to the treadmill tests while wearing different loads were compared using two-way ANOVA with repeated measures on one factor. Tukey HSD post hoc tests were used to determine which trials differed from one another. Regression analysis was used to correlate performance on the various tasks with each other, and performance on individual tasks with body mass and with lean body mass. Significance for all tests was judged at the 0.05 level.

CHAPTER III

RESULTS

In this study, 48 participants were recruited and completed at least one session. One participant was recruited, but excluded due to a preexisting metabolic condition. Forty-two participants (22 males, 20 females) completed all five sessions for the study and 6 withdrew. Four of these subjects withdrew due to scheduling difficulties, while 2 withdrew because of unrelated medical issues.

Anthropometric Variables

Demographic and anthropometric values for the participants are displayed in Table 1. Males had higher values for height, BM and LBM, while females had higher body fat percentages. Males and females did not differ significantly in age or BMI.

Table 1. Subject Characteristics (Mean ± SE)

	Age (yr)	Height (cm)*	BM (kg)*	BMI	Body Fat %*	LBM (kg)*
All n = 42	23.7 ± 3.9	170 ± 10	67.9 ± 9.8	23.5 ± 2.5	17.8 ± 8.2	56.0 ± 11.2
Males n = 22	24.3 ± 4.6	177 ± 9	73.0 ± 8.2	23.6 ± 2.2	11.3 ± 4.3	64.7 ±8.4
Females n = 20	23.1 ± 3.0	163 ± 6	62.3 ±9.4	23.4 ± 3.0	25.1± 5.0	46.5 ± 6.1

* Males vs. females, $p < 0.01$

Run Speed Correlations

Treadmill performance as measured by time to exhaustion was plotted against the speed of the 4.8-km run. This was done for the 0, 10, 20 and 30-kg trials (Figures 1-4). Data were plotted for all subjects and also for males and females separately. Correlation coefficients (r) were calculated for each plot. All r values were significant at the 0.01 level. For all subjects, males and females, correlation coefficients tended to decrease with increasing treadmill load, especially in the female participants (Table 2). Figures 1-4 show the plot for the combined data at all loads.

Table 2: Correlation between treadmill performance time and run speed

Treadmill Load	Correlation coefficient (r) with 4.8-km speed*		
	All	Males	Females
0 kg	0.87	0.75	0.83
10 kg	0.81	0.65	0.75
20 kg	0.82	0.73	0.68
30 kg	0.76	0.65	0.55
	Proportion of Variance Accounted for (r^2)		
	All	Males	Females
0 kg	0.76	0.56	0.69
10 kg	0.66	0.42	0.56
20 kg	0.67	0.53	0.46
30 kg	0.58	0.42	0.30

* All r values, $p < 0.01$

Figure 1: Treadmill time with 0-kg load vs. run speed for all participants

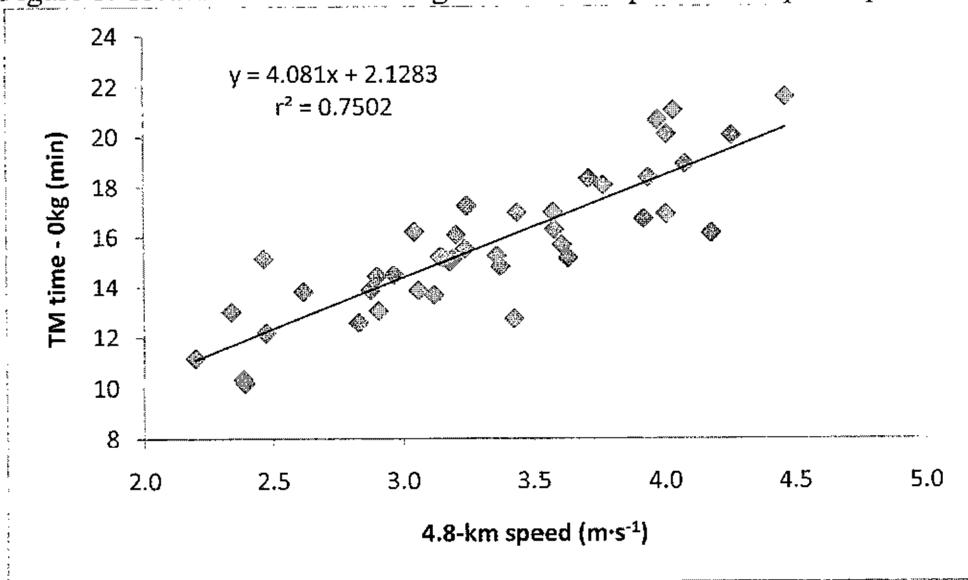


Figure 2: Treadmill time with 10-kg load vs. run speed for all participants

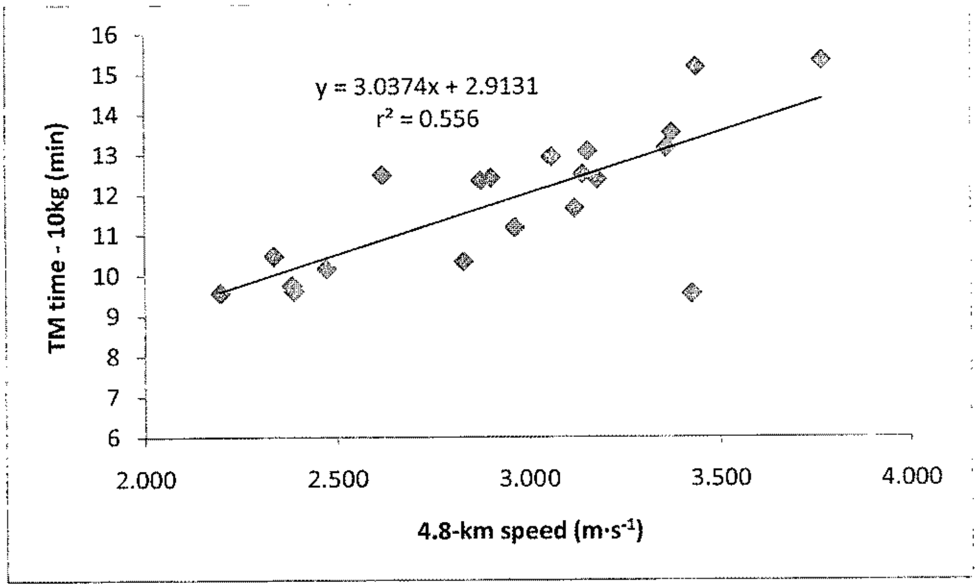


Figure 3: Treadmill time with 20-kg load vs. run speed for all participants

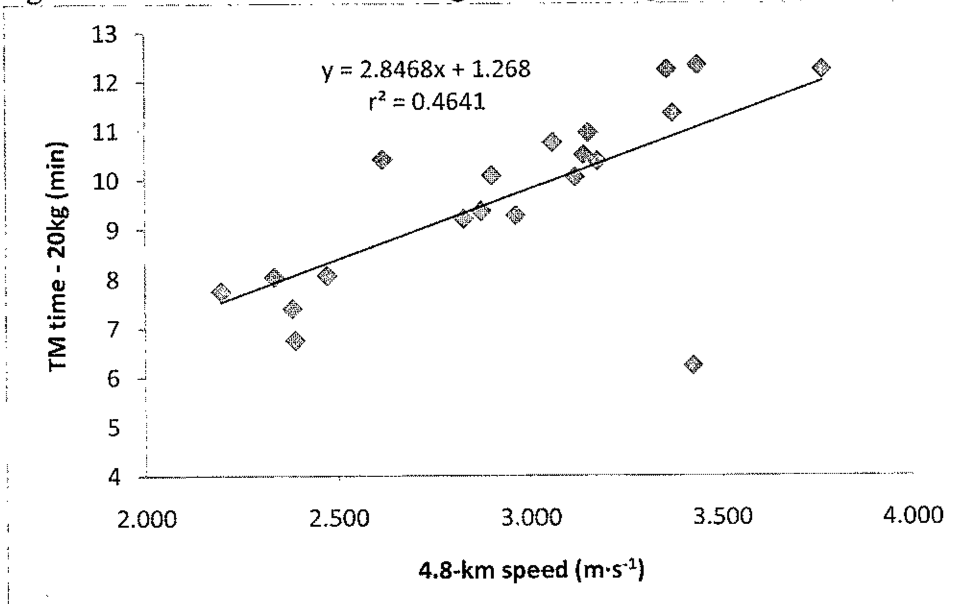
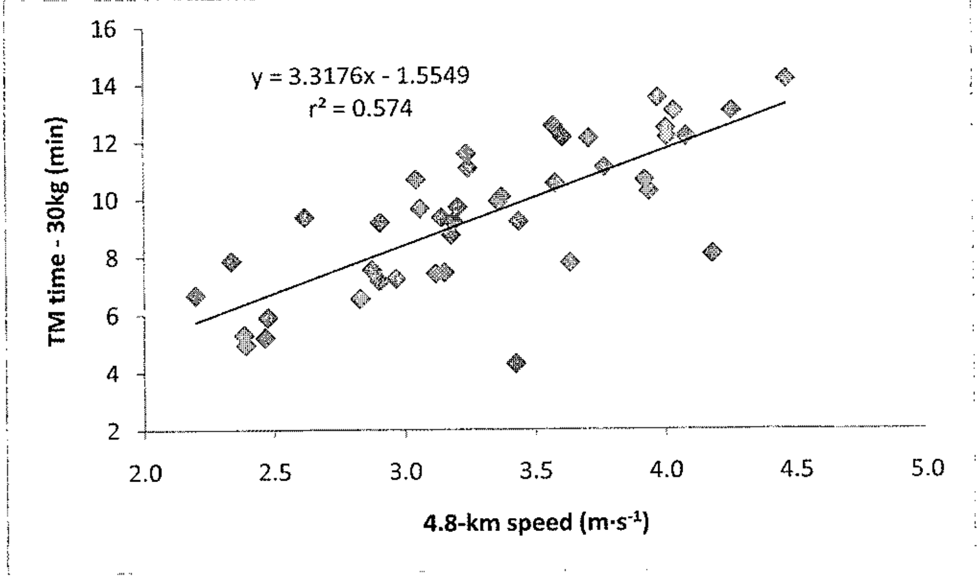


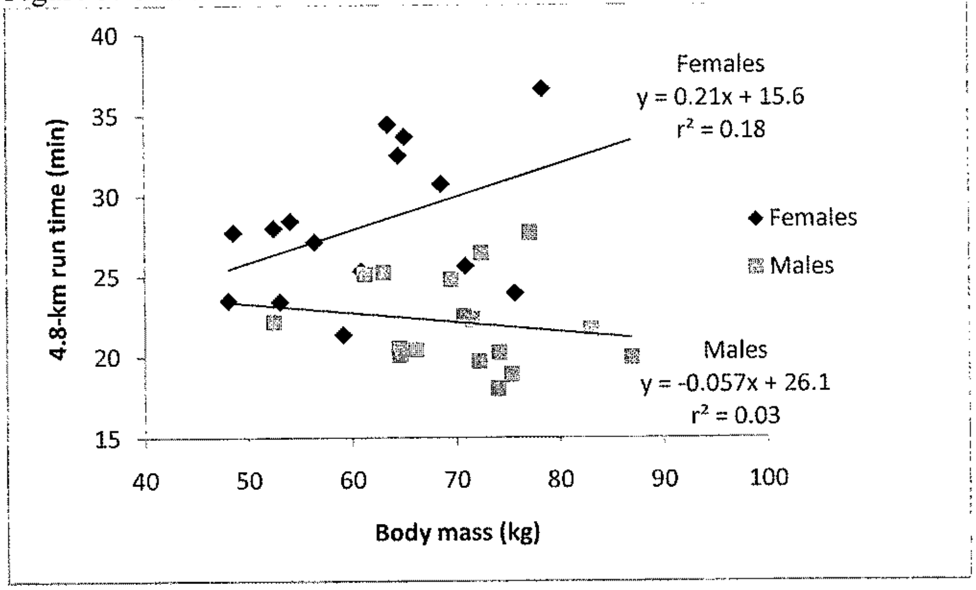
Figure 4: Treadmill time with 30-kg load vs. run speed for all participants



Body Mass Correlations

Given the greater BM of males and the expectation that their performance would exceed that of females, the relationships between BM and performance were analyzed separately for the two genders. Best fit regression lines were found for the correlation between BM and performance on all the aerobic tasks. Figure 5 displays the relationship between BM and 4.8-km run time. There was no significant correlation for either gender. Thus, individuals of smaller body mass did not perform better than individuals of larger BM.

Figure 5: Correlation of BM with 4.8-km run time



For performance on the treadmill tests, second degree polynomial regression lines were the best fit model for all the correlations, but only that for males in the 30-kg test was significant. Correlations of BM against performance for all tasks are given in Table 3. Figure 6 displays the regression for males in the 30-kg treadmill test, which shows that the optimum BM, yielding the best performance, was 92 kg. Given the lack of an effect of BM on most tasks, a post hoc assessment of the correlation of BM with VO_{2peak} on the 0-kg task (the most conventional of the aerobic tasks for measuring aerobic capacity) was performed, and is displayed in Figure 7. There was no significant relationship.

Table 3: Correlations between BM and aerobic task performance

Task	Correlation coefficient (r)	
	Males	Females
4.8-km run	0.12	0.34
Treadmill: 0 kg	0.34	0.25
10 kg	0.36	0.20
20 kg	0.38	0.16
30 kg	0.48#	0.32

* $p < 0.01$; # $p < 0.05$

Figure 6: Correlation between BM and male performance on 30-kg task

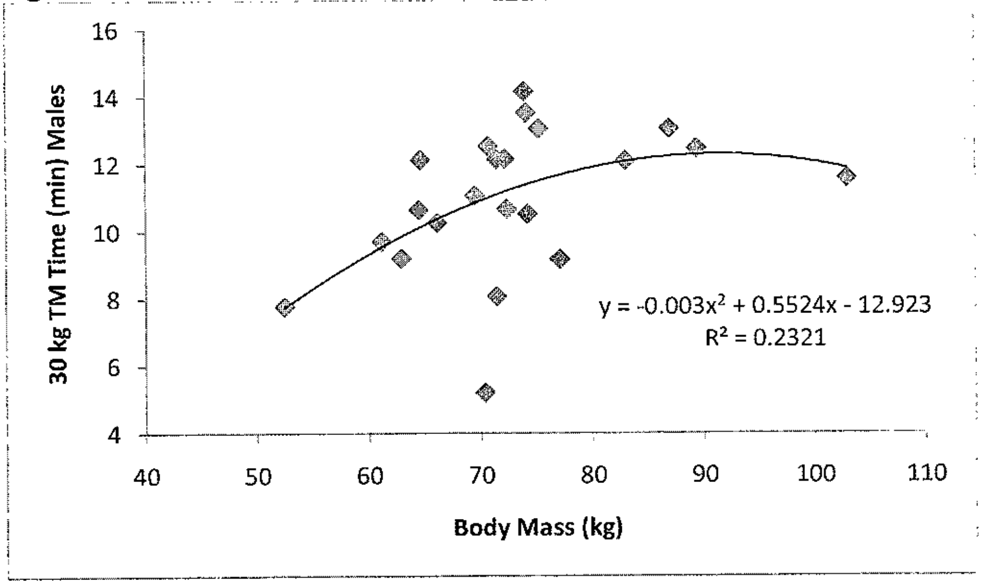
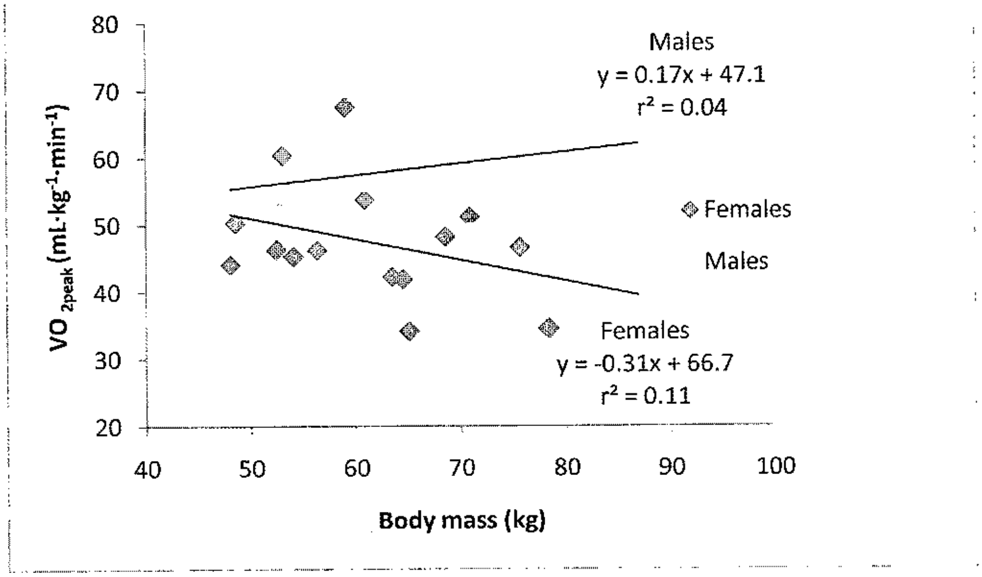


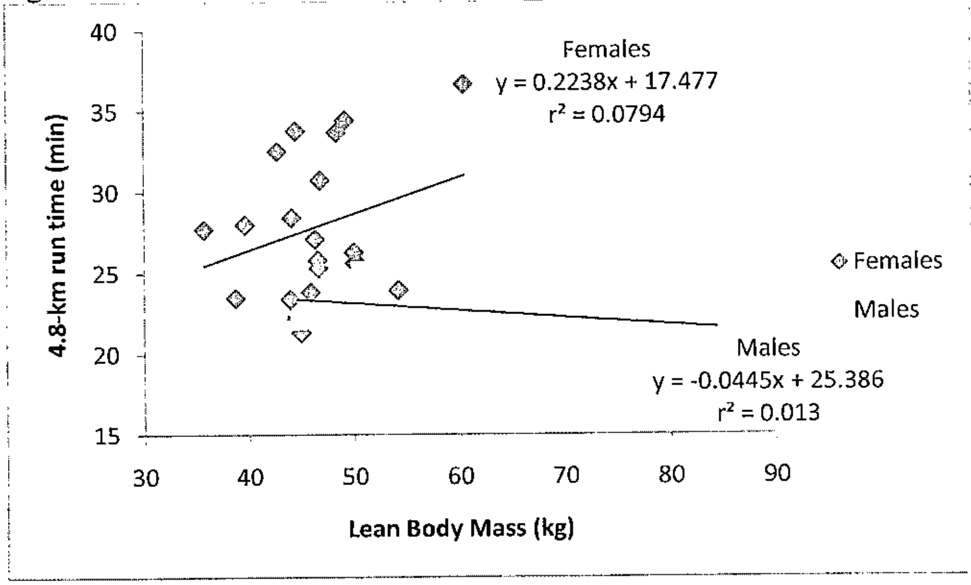
Figure 7: Correlation of BM with aerobic capacity on 0-kg task



Lean Body Mass Correlations

Given the greater LBM of males and the expectation that their performance would exceed that of females, the relationships between LBM and performance were analyzed separately for the two genders. Best fit regression lines were found for the correlation between LBM and performance on all the aerobic tasks. Figure 8 displays the relationship between LBM and 4.8-km run time. There was no significant correlation for either gender. Thus, individuals of smaller LBM did not perform better than individuals of larger LBM.

Figure 8: Correlation of LBM with 4.8-km run time



For performance on the treadmill tests, second degree polynomial regression lines were the best fit model for all the correlations, but only that for males in the 30-kg test was significant. Correlations of LBM against performance for all tasks are given in Table 4. Figure 9 displays the regression for males in the 30-kg treadmill test, which shows that the optimum LBM, yielding the best performance, was 82 kg. Given the lack of an effect of LBM on most tasks, a post hoc assessment of the correlation of LBM with VO_{2peak} on the 0-kg task (the most conventional of the aerobic tasks for measuring aerobic capacity) was performed, and is displayed in Figure 10. There was no significant relationship.

Table 4: Correlations between LBM and aerobic task performance

Task	Correlation coefficient (r) with body mass (kg)	
	Males	Females
4.8-km run	0.13	0.37
Treadmill: 0 kg	0.27	0.24
10 kg	0.34	0.25
20 kg	0.39	0.28
30 kg	0.47#	0.38

* $p < 0.01$; # $p < 0.05$

Figure 9: Correlation between LBM and male performance on 30-kg task

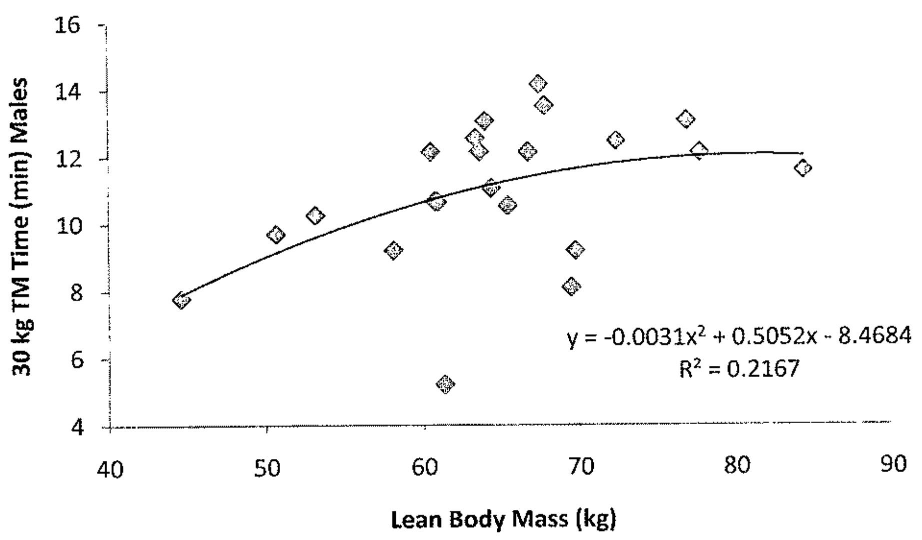
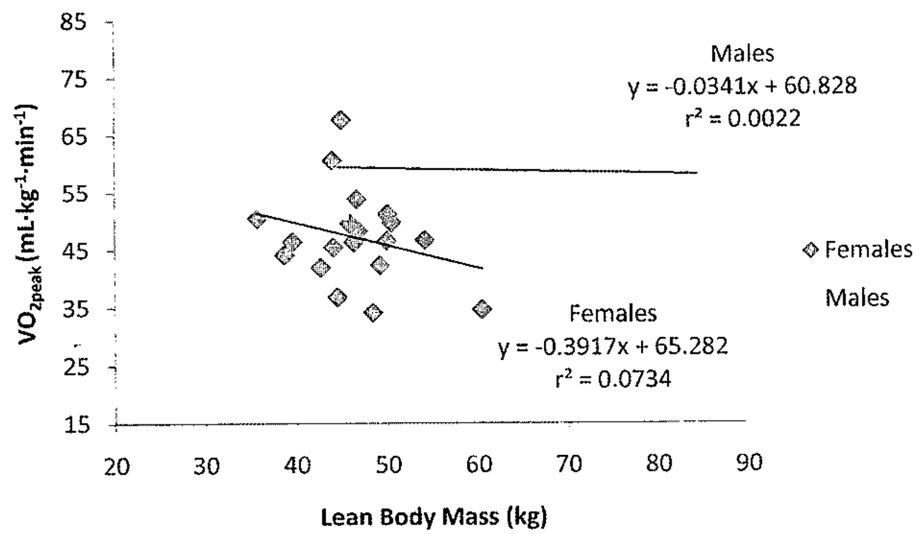


Figure 10: Correlation of LBM with aerobic capacity on 0-kg test



Pulmonary Function Measures

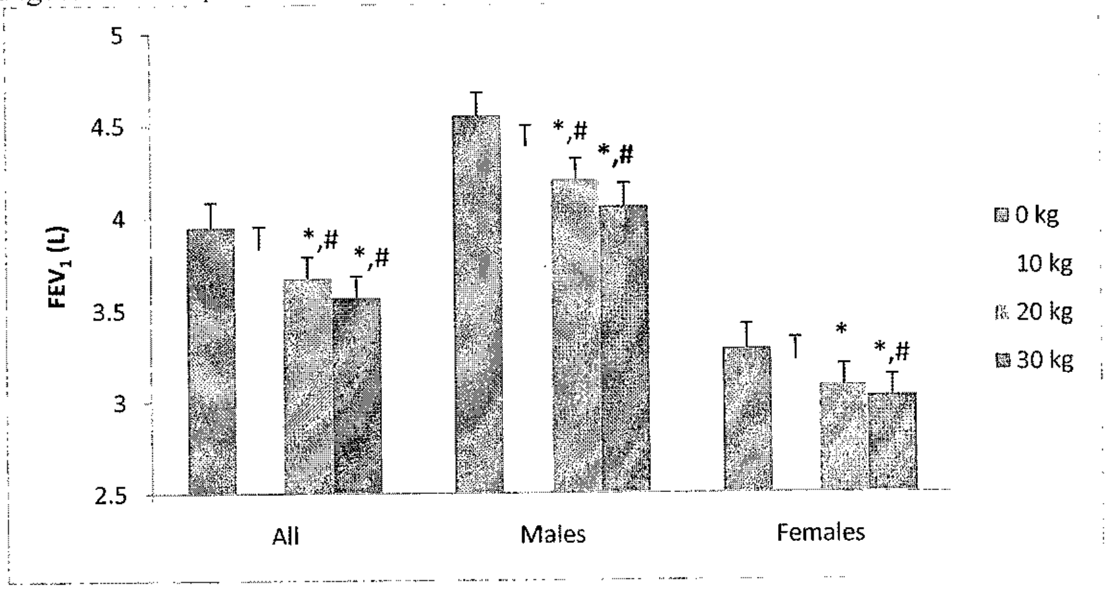
After performing 2-way ANOVA tests, it was found that there was a significant within-subjects effect with load for FEV_1, FVC, and MVV. All three measures decreased significantly with increasing load. For all three of these pulmonary measures, there was also a significant between-subjects effect with gender, with males significantly higher than females. There was no significant effect in either factor for FVC/FEV_1. No measures showed an interaction effect between trials and gender. Significant differences between trials are reported in Table 5, and Figures 15-17.

Table 5: Pulmonary function at 4 different loads (Mean ± SE)

Load (kg)	FEV_1 (L)	FVC (L)	FVC/FEV_1	MVV ($L \cdot min^{-1}$)
0	3.95 ± 0.13	4.79 ± 0.17	0.83 ± 0.01	146 ± 6.7
10	3.83 ± 0.12	4.64 ± 0.16*	0.83 ± 0.01	143 ± 6.8
20	3.67 ± 0.12*,#	4.46 ± 0.16*,#	0.83 ± 0.01	131 ± 6.4*,#
30	3.57 ± 0.12*,#	4.36 ± 0.15*,#	0.82 ± 0.01	129 ± 6.4*,#

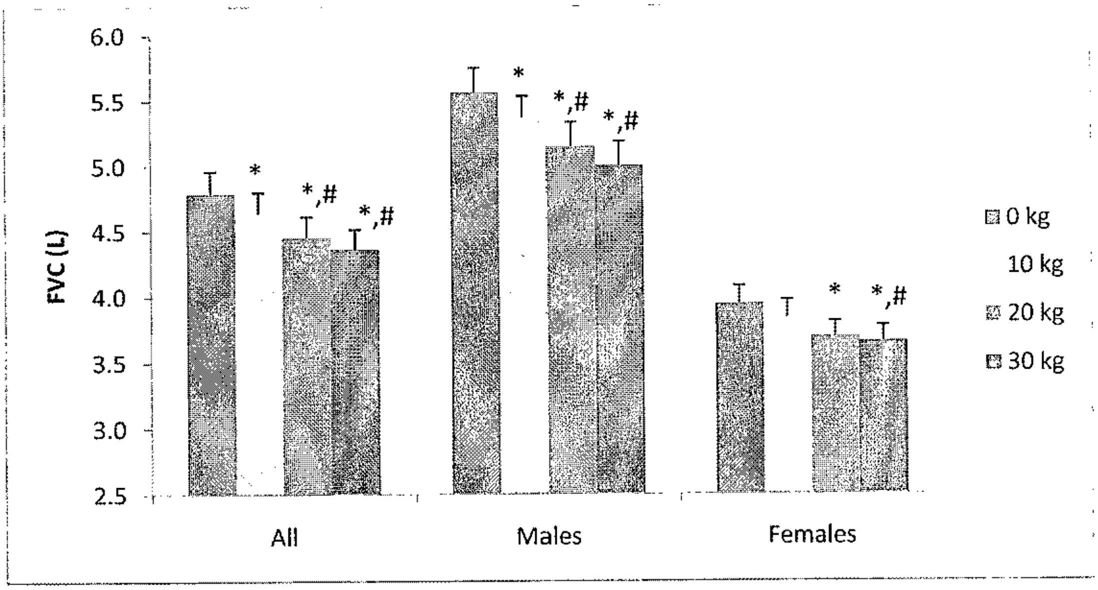
* $p < 0.05$ vs. 0 kg; # $p < 0.05$ vs. 10 kg

Figure 11: FEV_1 at 4 different loads



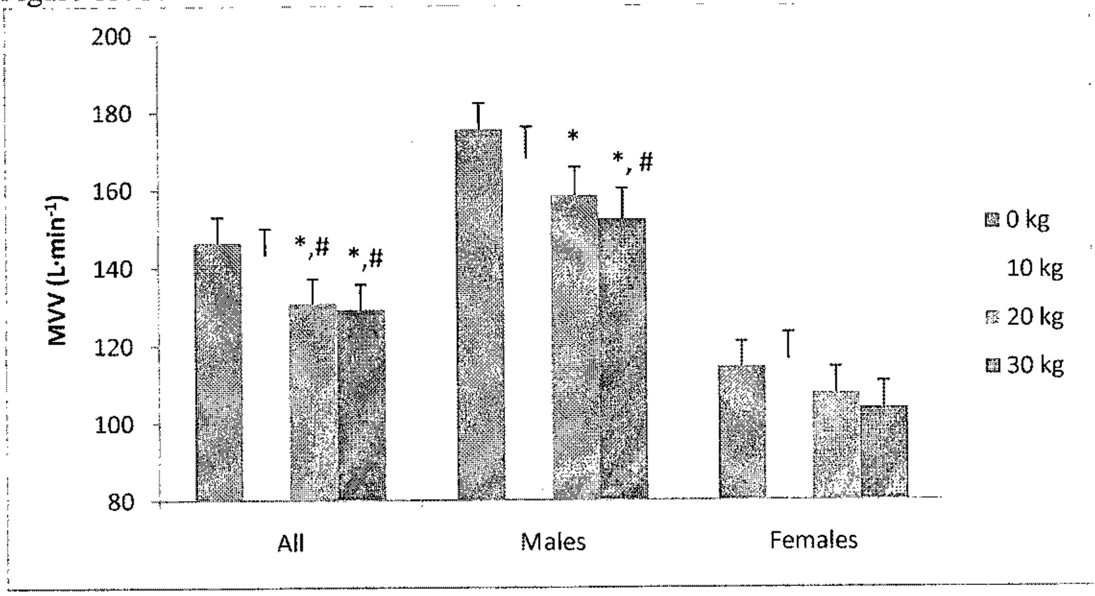
* $p < 0.05$ vs. 0 kg; # $p < 0.05$ vs. 10 kg

Figure 12: FVC levels at 4 different loads



* p < 0.05 vs. 0 kg; # p < 0.05 vs. 10 kg

Figure 13: MVV levels at 4 different loads



* p < 0.05 vs. 0 kg; # p < 0.05 vs. 10 kg

Exercise and Metabolic Function Measures

After performing 2-way ANOVA tests on all measures, it was found that there was a significant within-subjects effect with load for treadmill time, HR_{peak}, VO_{2peak}, and

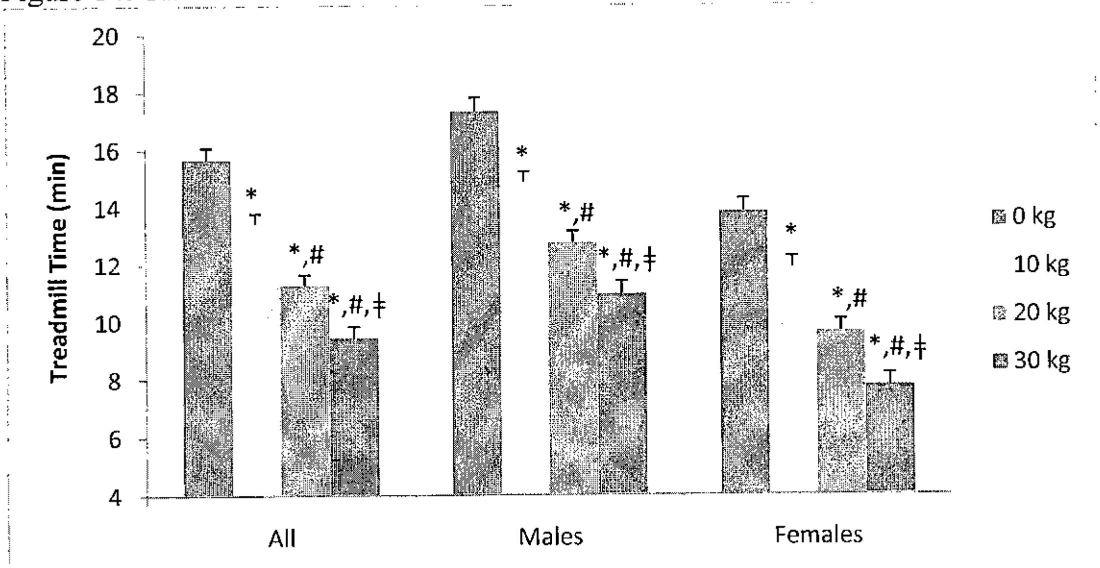
V_{Epeak}. All three measures decreased significantly with increasing load. Treadmill time, VO_{2peak}, and V_{Epeak} also showed a significant between-subjects effect with gender with males significantly higher than females. HR_{peak} did not show a between-subjects effect and no measures showed an interaction effect between trials and gender. There was no significant effect of load on RER_{peak} or $V_{E\,peak}$/MVV. Significant differences are reported in Table 6, and Figures 18-21.

Table 6: Exercise and metabolic function at 4 loads (Mean ± SE)

Load (kg)	TM Time (min)	HR_{peak} (bpm)	VO_{2peak} (mL·min^{-1}·kg^{-1})	RER_{peak}	V_{Epeak} (L·min^{-1})	V_{Epeak}/ MVV
0	15.66 ± 0.42	186 ± 1.4	53.1 ± 1.4	1.14 ± 0.01	114 ± 4	0.81 ± 0.03
10	13.45 ± 0.35*	185 ± 1.6	51.2 ± 1.2*	1.15 ± 0.01	109 ± 4	0.80 ± 0.03
20	11.29 ± 0.37*,#	183 ± 1.6	49.7 ±1.4*	1.14 ± 0.01	103 ± 4*,#	0.81 ± 0.04
30	9.45 ± 0.39*,#,¥	179 ± 2.1*,#,¥	48.3 ± 1.4*,#	1.15 ± 0.01	101 ± 4*#	0.82 ± 0.03

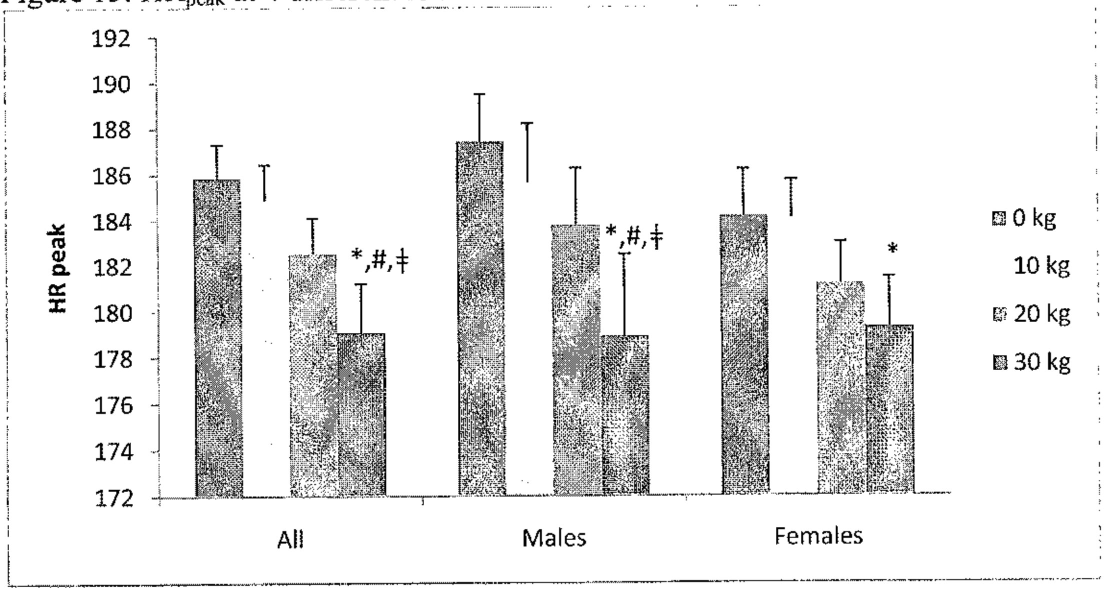
* $p < 0.05$ vs. 0 kg; # $p < 0.05$ vs. 10 kg; ǂ $p < 0.05$ vs. 20 kg

Figure 14: Time on the treadmill task at 4 different loads



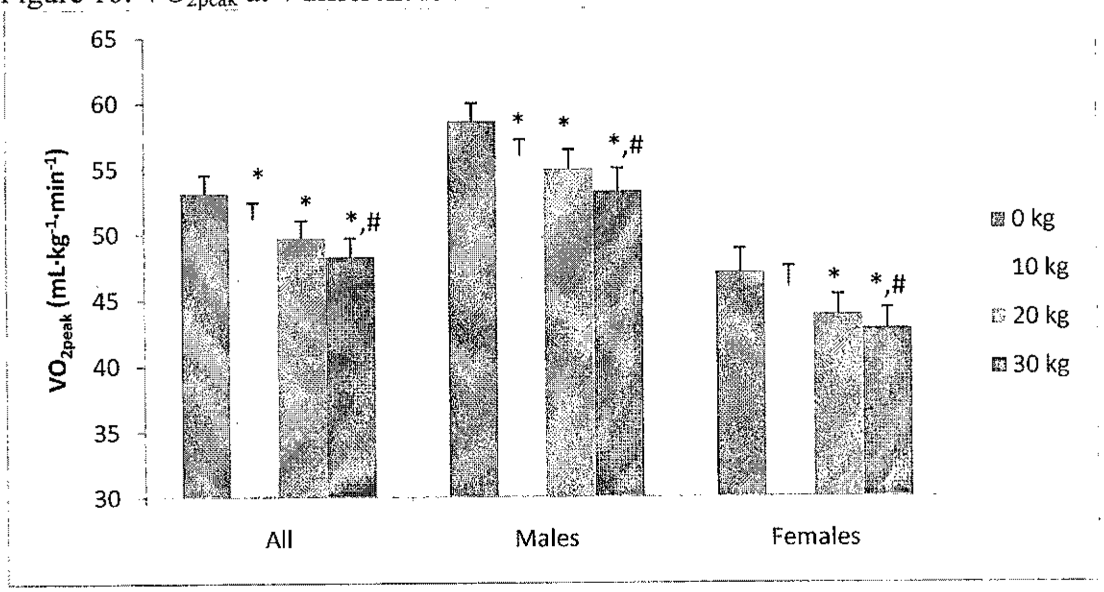
* $p < 0.05$ vs. 0 kg; # $p < 0.05$ vs. 10 kg; ǂ $p < 0.05$ vs. 20 kg

Figure 15: HR_{peak} at 4 different loads



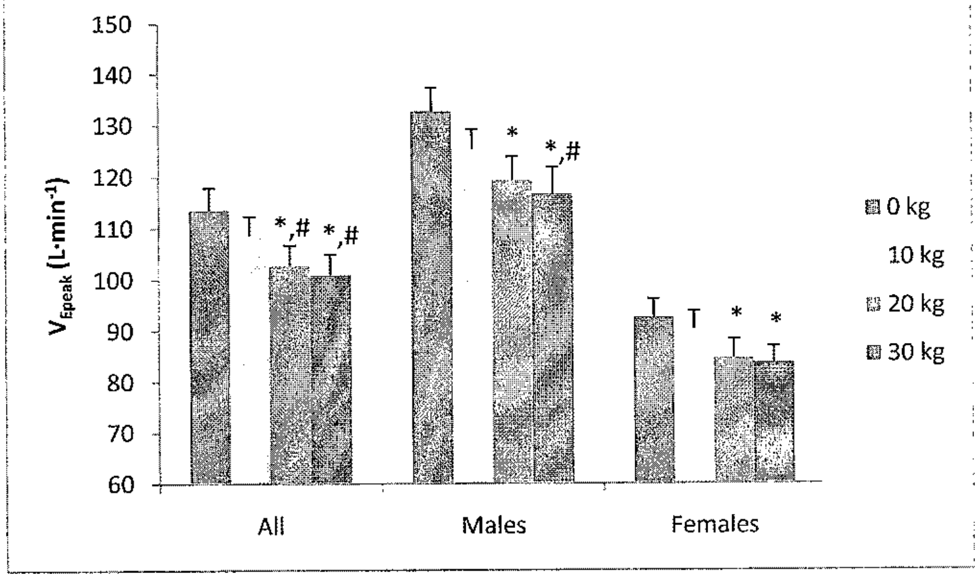
* $p < 0.05$ vs. 0 kg; # $p < 0.05$ vs. 10 kg; ǂ $p < 0.05$ vs. 20 kg

Figure 16: VO_{2peak} at 4 different loads



* $p < 0.05$ vs. 0 kg; # $p < 0.05$ vs. 10 kg

Figure 17: V_{Epeak} at 4 different loads



* $p < 0.05$ vs. 0 kg; # $p < 0.05$ vs. 10 kg

When performing a maximal exercise protocol, RER_{peak} of ≥1.1 is considered criterion for maximal exercise. The percentage of subjects reaching this level of exercise at each load is reported in Table 7.

Table 7: Percentage of subjects reaching RER_{peak} of ≥1.1

Treadmill Load	Percentage ≥1.1		
	All	Males	Females
0 kg	79%	77%	80%
10 kg	76%	70%	82%
20 kg	76%	80%	73%
30 kg	71%	70%	73%

CHAPTER IV

DISCUSSION

The purpose of this study was to determine if BM and added mass would have an effect on aerobic performance on a maximal treadmill task. Another purpose was to investigate the relationship between performance on the 4.8-km run and performance on loaded treadmill tasks. Significant differences in height, BM, LBM, and % body fat between male and female participants were evident (Table 1). Therefore, although the combined data were analyzed for trends, males and females were considered as separate groups for most results.

While BM did not have the expected effects, added mass did significantly affect both aerobic and pulmonary performance measures. Decreased performance on the treadmill tasks with increasing load supported the concept found in the literature that load increases energy cost of walking and running (Keren et al, 1981; Beekley et al., 2007; Pal et al., 2009). This study confirmed increased energy cost by showing significantly decreased treadmill performance with increasing load (Figure 14).

Run Speed Correlations

The most common test of aerobic fitness in the U.S. military is an unloaded distance run. One of the purposes of this study was to determine whether the 4.8-km run used by the Marine Corps correlates significantly with loaded aerobic performance for individuals with varying BM. To determine this, average run speed was calculated for each participant and plotted against performance on each treadmill task. Given that the treadmill task was a maximal exercise test, the best measure of performance was time to exhaustion.

Run speed was significantly correlated with performance for all treadmill tasks, including those carrying 20 and 30-kg loads (Table 2). However, as hypothesized, the correlation coefficients decreased in value with each increase in load, indicating that 4.8-km run time accounted for less of the performance variance when the load was increased. For males, the r^2 value decreased from 0.56 for the 0-kg task to 0.42 with the 30-kg task. This r^2 value indicates that only 42% of the variance in treadmill performance while carrying a 30-kg load can be explained by 4.8-km run speed. For females r^2 dropped from 0.69 to 0.30, indicating only 30% of variance in 30-kg performance accounted for by distance run speed (Table 2). Therefore, correlation strength between distance run speed and performance while carrying a 30-kg load is very low. This correlation might continue to decrease in strength if the load were increased further. Since combat loads can reach as much as 50-60 kg, a study could be done investigating correlations at these loads (Dean & DuPont, 2008). Further research may show that the correlation with 4.8-km run time would decrease to the point that it is no longer significant with higher loads.

Body Mass Correlations

In order to determine if there was a significant correlation between BM and performance on the aerobic tasks, BM of participants was plotted against their performance. Performance on the 4.8-km run was determined by the average run speed, and performance on the treadmill tasks was determined by time to exhaustion.

In contrast to the main hypotheses, BM and LBM were not significantly related to performance, other than by males on the 30-kg treadmill task. This was surprising, given that smaller individuals are well known to have greater body mass-relative aerobic capacity (VO_{2max} in $mL \cdot min^{-1} \cdot kg^{-1}$) than larger individuals, and better performance on body mass-related tasks, such as running without a load (Astrand and Rodahl, 1986; Swain, 1994). In this group of subjects, VO_{2peak} on the unloaded treadmill test did not show this classic relationship, suggesting that the fitness level of the subjects was not similar enough across the range of body mass to observe this effect.

A 2^{nd} order polynomial best fit regression line was calculated for each plot, allowing for the determination of an optimal body mass in the case of a significant correlation. It was hypothesized that each task would reveal an optimal BM for performance on that task. However, most of these regression equations proved to be insignificant (Table 3). The only significant correlation between BM and performance was in the male group for the 30-kg trial (Table 3; Figure 6). This finding led to an optimal BM of 92.1 kg, which is consistent with the hypothesis that larger individuals would perform better on the 30-kg treadmill task, and supports the findings of others showing that heavier individuals will perform better on tasks involving heavy load carriage. (Harman et al., 2008; Pandorf et al., 2002).

One of the significant limitations of this study was that participants had a wide range of fitness levels, as observed in the wide range of VO_{2peak} measurements (34.1 $mL \cdot min^{-1} \cdot kg^{-1}$ to 73.7 $mL \cdot min^{-1} \cdot kg^{-1}$ in the unloaded test). Researchers attempted to control for this variance by selecting only participants who self-reported at least 2.5 hours of vigorous physical activity each week. However, this amount varied greatly, with some participants reporting as much as 12 hours and others reporting just over 2.5 hours. Also, some participants may have overestimated their activity levels or included moderate activity in their estimation.

If a sample could be used in which all participants had a similar fitness level, correlations on the different tasks might not be as strong. Future research should repeat the procedure but recruit participants of a uniform fitness level. Such recruitment could be done by recruiting participants that have all recently finished a uniform training regimen like military special training or participants from a sports team.

Another limitation of the study was the narrow range of BM in the participants. Specifically, there were very few participants at the upper end of the BM range. If this study were to be repeated, it would be important that a wider range of BM is recruited.

Finding a population with a wide BM range that also has a narrow fitness range may be challenging for females. Highly fit females tend to have a narrow BM range due to their relative inability to build substantial muscle mass compared to males. In this study, the BM range for females (48.6 kg to 78.4 kg) was much smaller than the BM range for males (52.5 kg to 103.0 kg). However, it should be possible to find a male population with uniformly high fitness and a wide BM range.

Lean Body Mass Correlations

In order to determine if there was a significant correlation between LBM and performance on the aerobic tasks, LBM of participants was plotted against their performance. Performance on the 4.8-km run was determined by the average run speed, and performance on the treadmill tasks was determined by time to exhaustion.

A 2nd order polynomial best fit regression line was calculated for each plot, allowing for the determination of an optimal body mass in the case of a significant correlation. It was hypothesized that each task would reveal an optimal LBM for performance on that task. However, most of these regression equations proved to be insignificant (Table 4). The only significant correlation between LBM and performance was in the male group for the 30-kg trial (Table 4; Figure 9). Optimal LBM was found to be 81.5 kg, which is consistent with the hypothesis that larger individuals would perform better on the 30-kg treadmill task. The average LBM of the males in this group was 64.7 kg, much lower than the optimal value calculated.

The 2001 study by Lyons et al. indicated that LBM should show a stronger correlation than BM with performance on aerobic tasks while carrying a load. They concluded that increased body fat percentage significantly increased the energy cost of the task. In the current study, LBM did not show a stronger correlation with performance loaded treadmill tasks. Values of r^2 were similar for performance correlations with both BM and LBM (Tables 3, 4).

Pulmonary Function Measures

It was hypothesized that FVC, FEV_1, and MVV would all decrease with increasing load. The reasoning for this hypothesis was that it would be more difficult for the individual to inflate the lungs when wearing the load. The observed result supported this hypothesis (Table 5, Figures 11-13). Since the hypotheses stated that FEV_1 and FVC would both decrease with increasing load, it was also expected that FEV_1/FVC would not change significantly, which was also supported by the data (Table 5).

MVV also decreased significantly with increasing load. Since all measures of pulmonary function decreased, it can be concluded that increasing the amount of load carried decreases the general pulmonary function of the individual. These findings are consistent with the findings of prior research showing decreases in FEV_1 and FVC, with no change in FEV_1/FVC (Chow et al., 2005; Legg and Cruz, 2004; Bygrave et al., 2004;

Muza et al., 1989; Legg, 1988). These researchers pointed out that decreased FEV_1 and FVC with no change in ratio is similar to the effects of mild restrictive pulmonary disease (Muza et al., 1989).

Legg (1988) suggested that the effect on pulmonary function may be related to the tightness of fit rather than the actual mass of the load. This was suggested because his study showed a significant decrease in MVV between 0 and 10 kg and no significant change with 20 or 30 kg. The results of this study do not show this same pattern. Males demonstrated no significant decrease between 0 and 10 kg, and a significant decrease in both 20 and 30 kg from 0 kg. Females showed no significant changes, and actually increased slightly in MVV from 0 to 10 kg. This may indicate that the load for this study was worn more loosely than that used in Legg's study, or it may indicate that MVV is indeed related to the amount of load rather than the tightness of fit.

Exercise and Metabolic Function Measures

The first exercise measurement taken was the time to exhaustion on the treadmill. This measure was used to indicate aerobic performance on the maximal treadmill tasks and also showed the most significant effect with load. All groups showed a significant decrease from each trial to the next with increasing load. The hypothesis was strongly supported in this case, that increasing load would result in decreased time to exhaustion. The participants were becoming fatigued earlier while carrying a load (Table 6, Figure 14).

The next exercise measurement was VO_{2peak}. It was determined that the measurement should be called VO_{2peak} and not VO_{2max} because subjects were expected to not reach a true aerobic maximum due to muscular fatigue with increasing load. There was a decrease in VO_{2peak} with increasing load as expected (Table 6, Figure 16). There was also a significant decrease in HR_{peak}, supporting the idea that participants were not able to achieve maximal aerobic exertion when carrying a load (Table 6, Figure 15).

RER is generally considered a good indicator of the relative intensity of exercise for an individual, with values ≥ 1.10 considered an indication of maximal or near maximal exercise. Based on this criterion, RER is expected to reach a maximum when maximal exercise intensity is reached, corresponding with VO_{2max} and HR_{max}. The hypothesis stated that, since VO_{2peak} and HR_{peak} would decrease with increased load, RER_{peak} would also decrease.

However, that result was not observed in this study. While VO_{2peak} decreased with increasing load, RER_{peak} showed no significant change (Table 6). While some research exists in which RER was measured carrying a load (Quesada et al., 2000), no studies were found in which RER_{peak} or RER_{max} were measured carrying a load. Therefore, it is impossible to say whether the results of this study are supported by the literature. Future studies should examine whether RER_{peak} remains linked to VO_{2peak} while a load is being carried.

One possible explanation for RER_{peak} not decreasing is that increasing load resulted in more lactic acid buildup in the skeletal muscle due to local muscle fatigue. Increased lactic acid from the anaerobic energy system would require more blood buffering, which increases the amount of carbon dioxide in the blood to be filtered out by the lungs. This would suggest a muscular limitation. However, the decreased VO_{2peak} could also be explained by the decreased pulmonary function (MVV) with load.

V_{Epeak} was recorded for each treadmill task. The hypothesis stated that V_{Epeak} would decrease with increasing load, which was supported by the data (Figure 17, Table 6). The ratio of V_{Epeak} to MVV was analyzed as well to determine if the primary cause of decreased performance was due to pulmonary constraint or if there were other factors also in play. V_{Epeak}/MVV showed no significant change with load. Similar decreases in MVV and V_{Epeak} suggest that one reason for lower exercise performance on the treadmill task was due to pulmonary constraint.

Conclusion

The main purpose of this study was to determine if there was an effect of BM or LBM on aerobic performance while carrying load. The results of the study did not support a correlation between aerobic performance on loaded tasks and BM or LBM. Therefore, an optimal BM or LBM could not be found for most of the tasks and so it cannot be determined if the optimal BM increases with load. The only exception to this is that males did show a significant correlation between BM and LBM and performance on the 30-kg trial. If a study were repeated with subjects of a more uniform fitness and a wider range of body masses, this correlation may become clearer. A correlation may also become stronger if heavier loads are used. Dean and DuPont found that loads of up to 60 kg are carried in military situations (2008).

The most significant results were found in the pulmonary and metabolic measurements. All pulmonary measurements decreased significantly with increasing load. The FEV_1/FVC ratio was found to stay consistent, even though FVC levels decreased. This shows that subjects' ability to inflate the lungs was decreased to the point that it also decreased their ability to exhale. The pattern of decreased FVC and FEV_1 with no change in ratio is characteristic of mild restrictive respiratory disease, such as interstitial lung disease or obesity (Muza et al., 1989, Wang & Cerny, 2004). Carrying a load in the form of a weighted vest and backpack appears to restrict inflation of the lungs, and therefore, the subject's ability to ventilate at rest and during exercise.

The metabolic measurement of VO_{2peak} decreased significantly with increasing load, showing that participants were not able to achieve the same level of aerobic work while carrying a load. However, the RER_{peak} levels, which would be expected to decrease with VO_{2peak}, stayed at a consistent level across all loads. This finding was unexpected and did not support the hypothesis. Further research needs to be done to determine a physiological explanation for this lack of correlation between VO_{2peak} and RER_{peak}.

The decrease in r^2 values with increasing load in the correlation between 4.8-km run speed and treadmill performance, indicates that the distance run is not a good measure for evaluating fitness for loaded tasks. Therefore, serious consideration should be given to alternative fitness tests using more occupationally relevant tasks for military fitness evaluations.

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APPENDIX I

EXERCISE TEST SCREENING QUESTIONNAIRE

Read the questions to potential subjects and interpret the responses. Do not have the person fill out the questionnaire on his/her own.

Name ______________________________ Sex ____ Age _____ Date ____________

Phone _____________________ email ____________________

I. Risk Factors

____ 1. Do you have a family history of heart disease? [heart attack, bypass surgery, angioplasty or sudden death prior to the age of 55 (father or brother) or 65 (mother or sister)]

____ 2. Have you smoked cigarettes in the past 6 months?

____ 3. Do you know if your blood pressure is typically 140/90 or more? Do you take blood pressure medication?

____ 4. Do you know if your LDL cholesterol is more than 130, or if your HDL cholesterol is less than 40? If you don't know your LDL, do you know if you total cholesterol is more than 200?

____ 5. Do you know if your fasting glucose is more than 100?

____ 6. What is your height and weight? [determine if BMI is > 30]

____ 7. Over the past 4 weeks, how much physical activity have you typically gotten each week? Consider moderate intensity activities, such as walking, slow bicycling, and gardening, and also consider vigorous intensity activities such as jogging, fast bicycling, and competitive sports. [physically active is at least 150 min/wk of moderate intensity, or at least 75 min/wk of vigorous, or a combination of the two, in which time spent in vigorous activities is doubled and added to time spent in moderate activities; less than this is considered sedentary, and a risk factor; twice this level is considered highly active]

II. Symptoms

____ 1. Do you ever have pain or discomfort in your chest or surrounding areas? (i.e., ischemia)

____ 2. Do you ever feel faint or dizzy? (Other than when sitting up rapidly)

____ 3. Do you find it difficult to breathe when you are lying down or sleeping?

____ 4. Do your ankles ever become swollen? (Other than after a long period of standing)

____ 5. Do you ever have heart palpitations, or an unusual period of rapid heart rate?

____ 6. Do you ever experience pain in your legs? (i.e., intermittent claudication)

____ 7. Has a physician ever said you have a heart murmur? (If yes, has he/she said it is OK, and safe for you to exercise?)

___ 8. Do you feel unusually fatigued or find it difficult to breathe with usual activities?

III. Other

___ 1. Do you have any of the following diseases? Heart disease, peripheral vascular disease, cerebrovascular disease, chronic obstructive pulmonary disease (emphysema or chronic bronchitis) asthma (chronic), interstitial lung disease, cystic fibrosis, diabetes mellitus, thyroid disorder, renal disease, or liver disease
___ 2. (For women) Do you think you may be pregnant?
___ 3. Are you taking any medications, such as blood pressure medication, that would affect your heart rate?
___ 4. Do you have any problem that might make it difficult for you to do strenuous exercise?

Eligible for study if: Is between 18-44 years old, has no more than 1 risk factor from section I, has none of the symptoms in section II, answers "No" to all questions in section III, AND the person must be considered highly physically active (see question 7 in section I), meaning they must report engaging in **at least 2.5 hours of vigorous** physical activity per week over the past 4 weeks.

Note: For individuals who do not know their blood glucose or blood lipid values, the ACSM assumes they have those risk factors if they are males over 44 years of age or females over 54 years of age, and assumes they do not have those risk factors if they are younger. Since all subjects in the current study will be 44 years old or less, if they do not know their blood values they will be assumed to not have those risk factors.

APPENDIX II

INFORMED CONSENT DOCUMENT
OLD DOMINION UNIVERSITY

PROJECT TITLE: Effect of body mass and added mass on treadmill performance

INTRODUCTION

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES. The research project will take place in the Human Performance Laboratory, room 2003 of the Student Recreation Center.

RESEARCHERS

David P. Swain, PhD, Responsible Project Investigator
Stacie I. Ringleb, PhD
Marlene DeMaio, MD
Rachel Walker
Courtney Butowicz
Carmine Grieco
Andrew Thompson

DESCRIPTION OF RESEARCH STUDY

Military personnel engage in strenuous physical activity in various types of adverse environments carrying substantial added mass in the form of gear and equipment. The purpose of this study is to determine how this added mass affects performance on a hill climbing task on a treadmill.

If you decide to participate, you will come to the exercise science laboratory facilities at Old Dominion University for about five hours of testing, about one hour each on five occasions spread out over 1-2 weeks. You should already have filled out a questionnaire to assess your current level of physical activity and your health risks. If you are eligible for the study and agree to participate, you will first be asked to don a vest, helmet and backpack with a total mass of 30 kg (66 lb) and climb a flight of stairs. Depending on your performance on this task, you will then participate in the rest of the testing. Approximately 60 individuals will participate in this study.

Body composition: Your height and mass while wearing tight fitting shorts or a bathing suit will be measured on a balance scale. Then, you will sit in a chamber to have your percentage of body fat measured. Also, the thickness of your skin and underlying fat will be measured with calipers at three sites.

3-mile run: You will run a distance of three miles as fast as possible, and your time will be recorded. You will wear a chest strap heart rate monitor during this run to record your heart rate.

Lung function: You will wear a mouthpiece and a nose clip and you will breathe in as deeply as possible and then exhale as fast and fully as possible for one breath. Then, you will be asked to breathe as deep and as fast as possible for 15 seconds. These tests will occur in a standing posture. These tests will be performed once with no added equipment, and then once before each of the treadmill tests below wearing the equipment indicated.

Treadmill test: You will be fitted with a chest strap heart rate monitor, a mouthpiece, nose clip and a head support for the collection of the air you exhale. You will then walk on a treadmill at increasing speeds and grades until you reach exhaustion. During the treadmill test, your heart rate, breathing and oxygen consumption will be measured.

The treadmill test will be done on four separate occasions. On one occasion, you will wear a vest and helmet with a combined mass of 10 kg (22 lb). On another occasion, you will wear the vest and helmet, and also wear a backpack of 10 kg (22 lb), for a total mass of 20 kg (44 lb). On a third occasion, you will wear the vest and helmet, and also wear a backpack of 20 kg (44 lb), for a total mass of 30 kg (66 lb). On a fourth occasion, you will not wear a vest, helmet or backpack. The four tests will not necessarily be in this order.

EXCLUSIONARY CRITERIA

You should have completed a health screening questionnaire to determine if you are eligible for the study. You must be between the ages of 18 and 44 years. To the best of your knowledge, you should not have cardiovascular disease, pulmonary disease, diabetes mellitus, any symptoms of these diseases, or more than one known coronary disease risk factor. If you are taking any medication that affects heart rate, you may not participate in the study. If you think you may be pregnant, you may not participate in the study. You must be considered physically active to participate in the study.

RISKS AND BENEFITS

RISKS: If you decide to participate in this study, then you may face a risk of abnormal blood pressure, fainting, irregular, fast or slow heart rhythm, and in rare instances heart attack, stroke or death during the exercise testing. Also during the exercise testing, you may face a risk of musculoskeletal injuries to the back or the lower extremities (such as legs, knees, ankles). The risk of serious consequences is considered to be low because of your health status as described under the exclusionary criteria. Also, you will be carefully monitored during testing. Should an emergency situation arise, EMS would be contacted and CPR begun. An automated external defibrillator will be in the building during testing, and available for use if needed. Phone access to EMS is available in the testing room. Finally, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: You may benefit by learning your aerobic capacity and body fat percentage.

COSTS AND PAYMENTS

If you complete all testing you will receive $30 to compensate you for your time. Students in participating Exercise Science courses may choose either $30 or research credits. If you are a student in a participating Exercise Science class, you will receive research credits that may be applied as extra credit. You will receive 5 credits if you complete all testing. Alternative means of obtaining this credit are available. You do not have to participate in this study in order to obtain this credit.

NEW INFORMATION

If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you.

CONFIDENTIALITY

Information collected about you will be kept confidential by the researchers. The results of this study may be used in reports, presentations, and publications; but the researcher will not identify you.

WITHDRAWAL PRIVILEGE

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision will not affect your relationship with Old Dominion University or the ROTC program, or otherwise cause a loss of benefits to which you might otherwise be entitled. The researchers reserve the right to withdraw your participation in this study, at any time, if they observe potential problems with your continued participation.

COMPENSATION FOR ILLNESS AND INJURY

If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of injury or illness arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury or illness. In the event that you suffer injury or illness as a result of participation in this research project, you may contact Dr. George Maihafer, the chair of the Institutional Review Board, at 757-683-4520, who will be glad to review the matter with you.

VOLUNTARY CONSENT

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them:

Dr. David Swain, 757-683-6028

Ms. Rachel Walker, 683-3133

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. George Maihafer at 757-683-4520 or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

Subject's Printed Name & Signature	**Date**

INVESTIGATOR'S STATEMENT

I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the subject's questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

Investigator's Printed Name & Signature	**Date**

VITA

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