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PHYSIOLOGICAL AND PERCEPTUAL RESPONSES TO LOAD CARRYING IN FEMALE SUBJECTS USING INTERNAL AND EXTERNAL FRAME BACKPACKS

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Eleven Female subjects (ages 18–33) walked on a motor-driven treadmill at 3.2 mph for one hour carrying 33% of their body weight. The grade of the treadmill alternated every 15 minutes from 0 to 3%. Each subject carried an internal frame backpack for one trial and an external frame backpack for another trial on a separate day. The variables measured during the two load-carrying experiments included oxygen consumption ($\dot{V}O_2$), heart rate (HR), respiratory exchange ratio (R), minute ventilation (V_E), and the ratings of perceived exertion for the chest (RPE-Chest), shoulders (RPE-Shoulders), and legs (RPE-Legs). There were no statistically significant differences found between the two packs for any of the metabolic, cardiorespiratory, or perceptual variables measured. The grade of the treadmill had a significant effect on $\dot{V}O_2$, R, $\dot{V}_E$, and HR regardless of the type of pack carried. Minute ventilation was the only physiological response to load carrying that was significantly influenced by exercise time. The values for RPE-Chest, RPE-Shoulders, and RPE-Legs were significantly increased by exercise time and treadmill slope, regardless of the type of pack frame carried. It was concluded that when a load is carried on the back, differences in backpack frame designs are not great enough to produce significant differences in the energy cost or perception of carrying a moderately heavy load.

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PREFACE

The data for this report were collected by investigators from The Human Performance Laboratory, Department of Health, Sport, and Leisure Studies, Northeastern University, Boston, MA 02115 and U.S. Army Natick Research, Development and Engineering Center, Individual Protection Directorate, Natick, MA 01760-5019. Data was collected from 1 January, 1990 to 1 June, 1990. This report describes the physiological an perceptual responses of female subjects carrying internal and external frame backpacks. The investigation was unfunded.

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Definition of Terms

Aerobic capacity (VO_2max). The maximum intake and utilization of oxygen by the body.

Body composition. The physical makeup of the body, consisting of fat and lean body weight.

Double pack. A pack in which half of the load is carried on the front of the torso and half is carried on the back.

Existence load. The fighting load plus the additional food, clothing, and individual equipment needed to survive the mission.

External frame pack. A backpack that is supported by a rigid frame which rides close to the back but keeps the pack off of the body.

Fighting load. The load carried on dynamic operations where enemy contact is expected. The soldier wears and carries only his clothing, load bearing vest or web gear, helmet, weapon, ammunition, bayonet, and rations. The total weight of the fighting load should not exceed 48 lb.

Internal frame backpack. A backpack that has two aluminum staves (supports) that are sewn into the back panel to provide some rigidity, yet allowing the load to ride directly on the back.

Minute ventilation (V_E). The amount of gas expired in one minute. V_E = tidal volume x breathing frequency.

Military occupational specialty (MOS). The specific job a soldier is assigned to perform.

Rating of perceived exertion (RPE). The subjective rating an individual reports for the degree of exertion he/she is experiencing.

Respiratory exchange ratio (R). The ratio of CO_2 produced to O_2 consumed which estimates the utilization of fat and carbohydrates as energy sources.

Rice bag. A bag supported on the back of the shoulders and held by its upper corners by each hand.

Sherpa load carriage. A bag slung on the back and supported by a strap around the forehead.

Yoke. A pole placed across the shoulders with the load hung from both ends equally divided.

Summary

Many studies have been conducted concerning the physiological effects of carrying heavy loads in male subjects. Relatively few load carrying studies have been conducted on female subjects. Several of the studies in load carrying have compared the methods used to transport heavy loads. The present study examined the differences between the metabolic, cardiorespiratory, and perceptual responses of female subjects carrying U.S. Army internal, and external frame backpacks. It was hypothesized that the internal frame pack would elicit lower metabolic and perceptual responses than the external frame pack because its center of gravity is closer to the body than that of the external frame pack.

Eleven female subjects carried 33% of their body weight while walking at 3.2 mph on a motor-driven treadmill, with the grade alternating every fifteen minutes between 0 and 3%. The data collected while walking on the treadmill included oxygen consumption, heart rate, minute ventilation, respiratory exchange ratio, and the ratings of perceived exertion for the chest, shoulders, and legs.

There were no statistically significant differences found between the two packs for any of the variables measured. However, regardless of the type of pack carried, it was found that VO_2, R, V_E, and heart rate measures were affected by the slope of the treadmill. Minute ventilation values were affected by exercise duration as well. The RPE values for the chest, shoulders, and legs were also affected by exercise time, and the slope of the treadmill.

Physiological and Perceptual Responses to Load Carrying in Female Subjects Using Internal and External Frame Backpacks.

I. INTRODUCTION

The carrying of heavy loads is a severe problem for the U.S. Infantry Soldier. Soldiers are faced with the problem of needing certain essential items to perform their mission while at the same time not overburdening themselves. The load carried is dependent upon the mission, enemy, terrain, troops available, and length of time (Army Development and Employment Agency, 1987).

Light Infantry Soldiers are required to exist on their approach march load (AML) for 48 h until Combat Service Support (CSS) is available for resupply (Ziomek, 1987). The AML consists of clothing, equipment, rations, weapons, and ammunition (Ziomek, 1987; Army Development and Employment Agency, 1987). The U.S. Army Infantry School recommends that the AML not exceed 72 lb (45% of the average 160 lb soldier) (Knapik, 1989). However, this 72 lb load is often exceeded due to the demands of the mission, and loads of over 100 lb are common in the infantry. Since the soldier is forced to carry such a great deal of weight, the only ways to decrease the burden are to lighten the individual components carried or employ less stressful methods of carrying the load.

Although efforts are made to lighten equipment, modern technology has resulted in an increase in the soldier's load. Actually, the addition of essential items such as body armor, and the increased need for communication equipment, has added to the weight of the soldier's burden.

The U.S. Army is highly concerned with the load being carried by the individual soldier. The Army has initiated the "Lighten the Soldiers' Load" campaign in an attempt to decrease the weight and develop less stressful ways to transport the load (Sampson, 1988).

The primary concern with the "Lighten the Soldiers' Load" campaign is developing ways to decrease the soldier's energy expenditure when carrying a load. This can be accomplished by either reducing or redistributing the weight of the load, decreasing the marching speed of the soldier, a decrease in the slope of the terrain, or a less stressful walking surface.

Through the development of new equipment, the U.S. Army Natick Research, Development, and Engineering Center has made an attempt at decreasing the energy expenditure of the soldier during load carrying. In 1988, the Army developed a state-of-the-art internal frame backpack, the Field Pack Large With Internal Frame (FPLIF), to replace the Large All-Purpose Lightweight Individual Carrying Equipment (Large ALICE) backpack with an external frame. The FPLIF and ALICE packs were designed to fit the 5th percentile female through 95th percentile male soldiers. The FPLIF weighs 8.0 lb empty and has an internal volume of 7500 in^3. The Large ALICE pack and frame weighs 7.0 lb empty and has a 4500 in^3 internal volume. The two packs differ in the position of the load relative to the individual's center of gravity, and the stability of the load.

Several studies have been conducted on U.S. Army male soldiers involving the various aspects of load carrying ability, including the types of carrying devices utilized. However, relatively few studies have investigated the effects of load carrying on female subjects. Due to the differences in body composition, strength, oxygen capacity, and anthropometry between the sexes, it would be expected that female subjects have different load-carrying capabilities than male subjects. Although female soldiers are generally not assigned infantry military occupational specialties (MOS) in the Army (Gaieski, 1989), they are still subjected to rigorous training that involves carrying heavy loads. Therefore, it is important that research be conducted on female subjects and the loads they must carry.

Statement of the Problem

The intent of this study was to compare female subjects' metabolic, cardiorespiratory, and perceptual responses to carrying an internal frame backpack versus an external frame backpack. An advantage of the internal frame pack is that it allows the center of gravity of the load to ride closer to the body. An advantage of the external frame is that it provides for a more stable load and is held off the back to allow more ventilation in that area. If differences in energy expenditure exist between these two carrying systems it could provide useful information to both the military and industry pertaining to the design of equipment for females in the armed services. This information could also be useful to the manufacturers of commercial backpacks for women

Delimitations

During each load carrying trial, the participants in the present study walked at 3.2 mph for one hour on a motor-driven treadmill. It would have been better to cover 7.0-12.0 miles per trial over a 2 to 5 hour time period to simulate the extreme distances soldiers must often traverse. However, such a study would be difficult to conduct due to the demands it would place on the subjects. The present study tested the subjects on a treadmill while controlling the speed, terrain, grade and environmental conditions. The environmental extremes a backpack user may face cannot be simulated in the lab. In field use, certain environmental conditions may cause differences in the physiological and perceptual responses between subjects wearing the two pack types. For example, conditions such as rugged terrain, or extreme heat or cold may affect the user of the two backpacks differently for each pack.

Another delimitation of the present study was that only one model of each type of pack was tested. It would have been better to test several different internal and external frame packs. This would provide a more complete comparison of the basic design differences between the two.

Due to the high cost of certain military clothing items and footwear, the subjects in the present study did not dress in military attire. The subjects wore shorts, athletic shoes, and cotton T-shirts. In field use, certain human factors could arise with uniforms or combat boots that were not tested in this study.

The subjects were tested while carrying 33% of their body weight, and walking at a constant speed. It would have been better to have the subjects carry several different weight loads, and walk at various speeds.

Hypotheses

The design of an internal frame backpack allows the center of gravity of the load to be carried closer to the body than that of an external frame backpack. Therefore, it was hypothesized that females carrying an internal frame backpack while walking would have lower metabolic, and cardiorespiratory responses than while carrying an external frame backpack. It was also hypothesized that the perceptual responses would indicate that the internal frame pack would be less stressful to carry than the external frame pack.

II. LITERATURE REVIEW

This literature review will focus on three major topics in load-carrying: 1) the physiological effects and limits of load-carrying, 2) the methods used to carry heavy loads, and 3) the differences that exist between men and women in load-carrying tasks.

Physiology of Load Carrying

In his literature review, Haisman (1988) states that the possible determinants of load carrying ability include age, anthropometry, aerobic and anaerobic power, muscle strength, body composition, gender, the subjective feelings perceived, the dimensions and placement of the load, biomechanical factors, the nature of the terrain, and the effect of climate and protective clothing. He states that the energy cost of carrying a load has been found to depend primarily upon the walking speed, body weight, load weight, gradient of the terrain, and surface type. Haisman also states that there is no obvious definition of a maximal load to be carried because of the large number of variables involved, but for young healthy males the consensus among investigators is that a load of approximately 1/3 body weight is optimal.

Brezina and Kolmer (cited in Cathcart, Richardson, and Campbell, 1923) confirmed work of prior investigators that the maximal economic velocity in load carrying is approximately 80-85 m/min, and that energy cost was not influenced by loads up to 1/3 body weight. That is, this amount of extra dead weight could be carried as economically as the same amount in extra live weight. They also maintained that it was more economical, with regards to energy expenditure, to increase the load rather than the speed at which the load is carried. In other words, the maximal economic velocity fell with loads increasing above 30% body weight.

Patton, Kaszuba, Mello, and Reynolds (1990) looked at the energy cost of prolonged load carrying at speeds and loads expected to be encountered by U.S. Army Light Infantry Soldiers, and the ability of these soldiers to perform high intensity anaerobic exercise of the upper and lower body immediately following load carrying. Fifteen male soldiers carried three different loads of 11.5, 69.4, and 109 lb in a Large ALICE pack at 2.5, 3.0, and 3.6 mph. They found the 109 lb load elicited a significantly higher energy cost than the 69.4 lb load at each speed. Significant increases in VO_2 (ml/kg/min), V_E (l/min), and heart rate (beats/min) over time were seen at all three speeds when carrying the 109 lb load. The 69.4 lb load produced significant increases in VO_2, V_E, and heart rate over time at 3.0, and 3.6 mph, but not at 2.5 mph. No changes were seen with time in these variables under any march speed for the 11.5 lb load. Patton et al. state a number of reasons that may account for the heavier work loads causing a gradual increase in VO_2 over time. These changes include reduced mechanical efficiency, increased body temperature, increased minute ventilation, increased blood lactate concentrations, and a shift in substrate utilization. For the ratings of perceived exertion (RPE) regarding upper body, lower body, and overall feelings there were significant increases over time for each speed and each load. They concluded that physiological and perceptual responses to load-carriage are not constant, but increase significantly over time when the load is 26% VO_2max or greater. For the upper body anaerobic power measurements, no significant differences were found for mean or peak power outputs following any of the load conditions compared to the unloaded condition at any speed. Significantly lower power outputs were found in the lower body when the 109 lb load was compared to no load following the 2.5 mph trial. However, no significant differences among loads were seen at the other speeds.

Epstein, Rosenblum, Burstein and Sawka (1988) studied six men walking for 120 min on a treadmill at 2.8 mph and 5% grade while carrying a backpack loaded with 55 lb and again with 88 lb. They showed that the energy costs of carrying 55 lb yielded a constant energy cost over time, while the 88 lb load yielded a significant increase in energy cost over time. This they attribute to the altered biomechanics of carrying a heavier load. They also stated that fatigue occurs quickly when carrying heavy loads once the work intensity reaches 50% of maximal work capacity. This agrees with data by Borghols, Dresen, and Hollander (1978) who found that for work loads higher than 50% VO_2max, the relationship between load and pulmonary ventilation is alinear in dynamic exercise. However, this workload is considerably higher than the relative workload reported by Patton et al. Patton attributed this discrepancy to differences in the fitness of the subjects, or to differences in the load carriage conditions, i.e. speed, loads, and length of march.

Shoenfeld, Udassin, Shapiro, Birenfeld, Magazanik, and Sohar (1978), tested 20 male subjects 18-21 years old marching at 6 km/h once for 6 km and once for 12 km with a backpack load of 30 kg (66 lb) or 35 kg (77 lb). They measured the following variables pre- and post-marching: mean heart rate, VO_2max, and rectal temperature. They found no significant differences between before and after measurements for the 6 km march with either load for the mean heart rate, rectal temperature, or VO_2max. For the 12 km march significant differences were found in an increase in mean heart rate, and a decrease in VO_2max between the two groups carrying 30 and 35 kg for 12 km. They found these differences to be supported by the subjective feelings of the participants. Therefore, they concluded that the optimal backpack load for healthy young men is 30 kg for a 6 km/h march for 12 km, and 35 kg for a 6 km/h march for 6 km on level pavement without considering the task too difficult.

To determine the optimal backpack load for women, Johnson (1983) looked at 10 women carrying loads of 0, 11, 22, 33, and 44 lb for 10 min on a motor driven treadmill at 3.1 mph and 0% grade. It was found that the optimal load was 22 lb expressed as 38.4% of the mean VO_2 max, ml/kg/min. This load represented 17.3% of the mean subject's body weight. This optimal load found by Johnson is not nearly as severe as the optimal load of 1/3 body weight normally reported for males. Therefore, women are likely to be more sensitive to heavy loads than men.

Methods of Load Carrying

Another area of focus has dealt with the types of load carrying modes employed around the world. The mode of load carrying varies with national origin, race, sex, and intelligence. Some of the modes of load carriage employed have included the head, hands, feet, torso (backpack), Korean A-frame (Daniels, 1956), yokes, rice bags, double pack, sherpa style, and hobo's bindle staff. Several investigators have made attempts to determine the best mode of human load carriage (Soule, Goldman, 1969. Legg, Mahanty, 1985. Legg, 1985. Datta, Ramanathan, 1971. Kinoshita, 1985). The studies conducted have been primarily concerned with metabolic data, with less attention being given to biomechanical studies. The literature remains unclear as to whether metabolic or biomechanical parameters are the most limiting factors in load carrying. It is likely to be a combination of the two.

Soule and Goldman (1969) compared the energy costs of loads carried on the head, hands, and feet in male subjects. The subjects walked for 20 min on a treadmill at speeds of 2.5, 3.0, and 3.5 mph under each of the following conditions: 1) no load; 2) carrying 4 kg (8.8 lb) in each hand; 3) carrying 7 kg (15.4 lb) in each hand; 4) carrying 14 kg (30.8 lb) on the head; and 5) carrying 6 kg (13.2 lb) on each foot. The increase in mean total energy cost (VO_2 ml/kg/min) for each load with increasing speed was significant. Most interestingly, they found that weight may be carried in the hands and on the head without a great increase in energy cost over equivalent body weight increases. However, when the weight was carried on the feet, the energy cost was greatly increased. Soule and Goldman concluded that although loads carried in the hands cost nearly twice as much per kilogram of body weight as loads carried on the torso, the penalty in energy cost for carrying a load in the hands is not considered extreme. However, the penalty for carrying loads on the feet is severe. The feet cannot be loaded except at the risk of increasing energy costs beyond what a person can tolerate.

Datta and Ramanathan (1971) conducted a comparative study of seven modes of carrying a 66 lb load at 3.1 mph on a level surface. They tested seven adult subjects. The gender of the subjects was not indicated in their report. They measured minute ventilation (V_E, l/min), V_E during recovery, O_2 consumption (l/min), heart rate, increments in heart rate due to work, and kcal expenditure. The seven modes employed were a rucksack, double pack, head, sherpa style, rice bag, yoke, and the hands. These investigators found that the mode of carrying influenced each of the six measured parameters significantly. It was found that energy cost, heart rate, and pulmonary ventilation changed significantly with the mode of carrying. The best to worst modes were double pack, head, rucksack, sherpa, rice bag, yoke, and hands. They also found that the variation among subjects was not significant for O_2 consumption (l/min, STPD), and energy expenditure (kcal/min), but was significant for the following cardiopulmonary parameters; heart rate, increments in heart rate due to work, and minute ventilation during work and recovery (l/min). Since oxygen consumption and energy expenditure did not significantly vary among subjects for the work levels in the trials conducted, they determined that the differences in the values of energy costs, heart rate, and pulmonary ventilation were due to the modes of carrying. However, it should be noted that their conclusion was based upon a small sample size.

Legg and Mahanty (1985) compared the energy costs of five modes of carrying a load close to the trunk. They looked at oxygen consumption, minute ventilation, and heart rate in five males walking on a level treadmill at 2.8 mph, for one h. The loads carried included the following configurations: 1) external frame backpack with 35% body weight (BW); 2) the same pack and load as configuration #1, but without the detachable frame; 3) external frame pack loaded with 17.5% BW and the other 17.5% in pouches on a U.S. Army equipment belt; 4) a double pack with 35% BW distributed evenly between the front and back; and 5) a flak jacket weighing 35% BW. Subjective measures were also taken. Unlike the findings by Datta and Ramanathan they found no statistically significant differences in the mean cardiorespiratory and metabolic costs associated with each of the five modes of load carriage. However, the double pack and flak jacket were subjectively rated as more comfortable than the pack with frame, and pack with no frame. It may be possible that Legg and Mahanty did not find metabolic differences between the load carriage modes, while Soule and Goldman, and Datta and Ramanathan did because the methods of load carriage were more similar in Legg and Mahanty's study. Also, Legg and Mahanty tested only five subjects which may raise statistical questions, and makes it more difficult to find true statistical significance.

Maloiy, Heglund, Prager, Cavagna, and Taylor (1986) walked five African women on a motorized treadmill at five different speeds carrying loads up to 34 kg (75 lb) in their customary manner, either on their head (Luo Tribe), or sherpa style (Kikuyu Tribe). They found that Luo and Kikuyu women could carry loads up to 20% of their body weight without increasing their rate of O_2 consumption over unloaded walking values. For heavier loads they found a proportional increase in O_2 consumption. That is, a 30% body weight load increased VO_2 by 10%, a 40% load increased the VO_2 by 20%. This is considerably more economical than the normal population. They report that in the normal population the O_2 consumption rate increases in direct proportion to the weight of the load as a percentage of body weight. That is, carrying a load of 20% body weight increases the VO_2 by 20%, and carrying a load that is 30% body weight increases the VO_2 by 30 percent. They suggest that these African women may be more economical because they minimize the movement of the load on their heads. These women may also experience some training effect or anatomical change since childhood that may account for carrying heavy loads more economically.

In the study cited earlier, Patton, Kaszuba, Mello, and Reynolds (1990) also compared the VO_2 (ml/kg/min), heart rate (beats/min), V_E (l/min), and RPE for upper body, lower body and overall feeling when carrying the U.S. Army Large ALICE Pack, and the U.S. Army Field Pack Large, with Internal Frame in 15 male soldiers. The subjects walked on a treadmill at 3.0, and 3.6 mph, at 0% grade for 12 kilometers. They carried each pack at both speeds, once loaded with 69.4 lb, and once with 109 lb. They found no statistically significant differences between the two packs in the metabolic measurements or RPE. However, the subjects were very fit male soldiers who had prior backpacking experience. Therefore, the influence of pack types may not have been as severe as it could be in less fit individuals.

Winsmann and Goldman (1976) measured the energy costs of male soldiers wearing one backpack with a waistbelt and one without a waistbelt. The subjects were studied while walking on a treadmill under the following conditions: 1) speed controlled by the investigator; 2) subject controlled speed; 3) heart rate controlled speed. They found no significant differences in energy cost between the two methods of load carrying. They concluded that as long as the weight is distributed over the body, the weight of the load is the most important factor in load carriage rather than specific load carriage system design.

Legg (1985) reports that it is difficult to clearly distinguish the physiological effects on the performance of the individual, from different methods of load carriage. Therefore, he states that it is important to supplement objective physiological measurements with subjective opinion in order to obtain the users input on comfort and fatigue.

Load Carrying in Men and Women

In studies comparing men and women in load-carrying tasks, metabolic, biomechanical, and performance type data has been gathered in a small number of studies. Many of these studies have shown interesting differences between men and women in load carrying.

Stauffer, McCarter, Campbell, and Wheeler (1987) studied 12 men and 12 women while walking during three minute intervals at 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, and 6.0 mph while carrying three different military load-bearing conditions of 11 lb, 26.4 lb, and 44 lb. The heaviest load was carried in a U.S. Army Medium ALICE pack without a frame. The lighter loads consisted of variations of a rifle and loaded equipment belt. They measured minute ventilation, tidal volume, respiratory rate, O_2 consumption in l/min and ml/kg/min, and respiratory exchange ratio. They found that United States Military Academy men and women responded differently to military load-bearing conditions, and have identifiable and quantifiable metabolic response differences to military load bearing. The metabolic costs were more severe in women.

Martin and Nelson (1985) looked at 16 males and 14 females performing a 25 yd sprint, standing long jump, agility run, reaction movement test, and ladder climb, under various load conditions. They found that performance levels decreased in a linear fashion in each task as load increased. They also found that males performed significantly better than the females on all tests under each of the load bearing conditions.

Martin and Nelson (1986) looked at several biomechanical factors in load carrying. They filmed 11 men and 11 women under high speed cinematography while walking overground at 4.0 mph. The subjects carried no load, 19.8 lb, 37.4 lb, 64 lb, and 79.2 lb. The two heaviest loads were carried in external frame backpacks. The variables measured included stride length, stride rate, single leg support time, double leg support time, swing time, and forward inclination of the trunk. They found that males and females displayed significantly different gait patterns during all load carriage conditions. In all the subjects, stride length and swing time decreased, while stride rate and double support time increased with increased load. There was also an increased forward inclination of the trunk with the two heaviest loads. As one would expect, the mechanical changes were more severe in the female subjects since the load they carried was a greater percentage of their lean body mass. The results showed that females were more sensitive to load magnitude and therefore should carry lighter absolute loads than men.

Bloom and Woodhull-McNeal (1987) photographed nine females and seven males while standing and wearing commercial internal and external frame backpacks. The packs were loaded with 42 lb for men and 31 lb for women. The positions of the knees, hips, shoulders, and ears were recorded. They found that both pack types caused forward lean. The bend was greatest above the hips, but both the knees and hips were also forward of the control position. The internal frame pack caused a greater displacement, and also greater uncompensated torque at the hips in all subjects. Men and women did not differ significantly from one another with respect to the positions of any body landmarks or centers of gravity while wearing either pack type. However, their subjective preferences differed significantly; 9 out of 10 men preferred the internal frame pack, while 8 out of 10 women preferred the external frame pack (subjective measures included four subjects who were added to the 16 who were photographed). The importance of including subjective measurements as stated in earlier references, (Legg and Mahanty, 1985; Legg, 1985), is further supported here by the findings of Bloom and Woodhull-McNeal.

Due to the physical differences between males and females, and because women show greater sensitivity to load magnitude than men (Martin, Nelson, 1986), it is reasonable to believe that men and women have different load carrying abilities. In this literature review it has been shown that studies involving men and women in load carrying tasks show significant differences in metabolic, biomechanical, and physical performance type measures.

III. PROCEDURES

This chapter describes the methods and procedures used to compare the metabolic, cardiorespiratory, and perceptual responses to prolonged load-carrying (33% of the subject's body weight) in females using internal and external frame backpacks. In addition, this chapter describes the methods and procedures used to measure maximal oxygen uptake during a continuous, multi-stage treadmill test, and the procedures used to determine percent body fat by hydrostatic weighing. The statistical methods used to analyze the test results are also described herein.

Subjects

Eleven healthy female volunteers, between 18 and 33 years of age, were recruited from the Northeastern University student body and the U.S. Army Natick, Research, Development and Engineering Center civilian workforce. The participants were required to have no known orthopedic problems. A written informed consent was obtained from each subject following a detailed explanation of the procedures (Appendix A).

All the subjects fell between the 5th and 99th percentile for the anthropometric measurements obtained on female soldiers (Gordon, Churchill, Clauser, Bradtmiller, McConville, Tebbetts, Walker, 1988.), since the packs were designed to fit these women.

Methods

All testing in the present study was conducted in the Human Performance Laboratory at Northeastern University under standard atmospheric conditions. Each subject reported to the laboratory for testing on three separate occasions. No special dietary or activity restrictions were placed upon the subjects while participating in the study. All the tests were conducted in the post-absorptive state (3-5 hours after a meal). Each subject was tested at the same time of day for all three test sessions.

The pack that is currently used by the U.S. Army is the Large, All-purpose, Lightweight, Individual Carrying Equipment (ALICE). It attaches to an external frame with the load distributed to shoulder straps, and to a greater degree, a waiststrap. The newly developed internal frame pack utilizes a state-of-the-art design in which the pack is carried close to the body, and the load is distributed between the shoulders and hips.

The Army does not have a proper load recommendation for women because the 45% body weight (BW) doctrine (described in chapter one) was determined for male soldiers only. The differences in the average lean body weight, maximal aerobic capacity, strength, and biomechanical parameters between men and women make it inappropriate to assume that women can carry as heavy a relative load as men. Also, the 45% BW doctrine includes the fighting load, clothing, and existence load, all of which are distributed over most of the body rather than focused on the back. The subjects in the present study carried only a pack with the load placed entirely on the back. Therefore, the investigators perceived 45% BW to be too heavy for women to carry at 3.2 mph for one hour. A load of 33% BW seemed more appropriate. This load closely agrees with several studies and reports which found the optimal backpack load to be one third of an individual's body weight (Army Development and Employment Agency, 1987; Cathcart, Richardson, Campbell 1923; Haisman, 1988; Knapik, 1989; Lothian, 1921-22.).

Each subject was assigned an identification number between 1 and 11 in the order in which they were tested. The odd-numbered subjects carried the external frame pack first, while the even-numbered subjects carried the internal frame pack first. During the second load-carrying trial each subject was tested while carrying the opposite pack.

On the first day of testing each subject was measured for body weight, stature (height), chest, waist, and buttock circumferences, crotch height, waist-back length, and percent body fat. Body weight measurements were obtained on a balance scale with the subject wearing only a bathing suit. Body weight was measured to the nearest quarter pound. Stature and crotch height were measured using an anthropometer. Waist-back length, and chest, waist, and buttock circumferences were measured using a steel tape. Stature was measured with the subject in the Frankfurt Plane (subject standing in the anatomical position with the corner of the eyes level with the top of the ear). The other anthropometric measurements were made in the standard anatomical position (Clauser, Tebbetts, Bradtmiller, McConville, and Gordon, 1988). All anthropometric measurements were made to the nearest millimeter.

Residual lung volume and body composition measurements were also obtained during the first test session. Residual lung volume was determined by the Nitrogen Washout Technique using a SensorMedics Horizon System 4400 metabolic cart (MMC) and the appropriate software. The subject breathed 100% oxygen through a mouthpiece connected to a turbine device. Three trials were conducted on each subject with ten minutes between trials to allow nitrogen levels in the lungs to return to normal. The average of the two lowest values was reported as the subjects residual lung volume.

Each subject was then weighed underwater to determine body density and to calculate percent body fat. The subject was given an explanation of the weighing technique and instructed to enter the underwater weighing tank to get accustomed to the water.

The subject was asked to work all of the air bubbles out of her bathing suit and hair. She then performed three or four practice maximal exhalations underwater to get accustomed to the feeling of complete exhalation. The subject was then comfortably seated on the weighing seat without touching the bottom or sides of the tank. The seat was suspended from a Chatillon scale, with the movement dampened by the researcher. The subject was asked to begin exhaling before submerging her head and to continue exhaling to her full vital capacity while completely submerged. Eight to ten weight measurements were taken with the average of the three heaviest trials used to determine body density.

The following equation (Buskirk, 1961) was used to determine body density.

$$\text{Body density} = \cfrac{Wa}{\cfrac{Wa-(Ww-Sw)}{H_2O \text{ density}} - (RV+100 \text{ ml})}$$

Where Wa = body weight in air, Ww = body weight in water, Sw = seat weight, RV = residual lung volume, and 100 ml is the estimated air volume of the gastrointestinal tract.

The body density value was then inserted into the Siri equation to determine the percent body fat.

$$\text{(Siri) \% fat} = \frac{495}{\text{body density}} - 450$$

Also on the first day of testing, the subject performed a maximal graded exercise test (GXT) on a Quinton 65 motor-driven treadmill in accordance with the Modified Bruce Protocol. Each stage of this protocol lasted three minutes and the test continued until the subject reached volitional exhaustion. Stage one began at 1.7 mph and 0% grade. After the initial stage, the test proceeded according to the original Bruce Protocol (Appendix B).

During the GXT the subject breathed through a mouthpiece attached to a turbine device. The subject's respired gas was continuously sampled by a SensorMedics metabolic cart for breath-by-breath determination of metabolic and ventilatory variables. Determination of maximal values for VO_2 (VO_2max) and V_E (V_Emax) were made from a one-minute running average of the data. Heart rate was monitored continuously and recorded during maximal exercise using a three channel Quinton 4000 Electrocardiograph with oscilloscope. Maximum exercise heart rate (maxHR) was determined by dividing 7500 by the distance (mm) of five R-R intervals from a reference R-wave.

The maximal exercise test was used to establish baseline fitness levels and to help familiarize each subject with walking on a treadmill. In addition, maximal exercise data were used to determine the percent VO_2max and percent HRmax values obtained during the two backpack trials.

During the second and third experimental test sessions, each participant carried one of the two backpacks loaded with 33% of her body weight on that day. The pack weight was adjusted to the nearest quarter pound. Each pack was uniformly loaded so that the center of gravity of the load was as close to the center of gravity of the pack as possible. The packs were individually fitted to each subject by a U.S. Army Load Carrying Equipment Technologist.

Immediately prior to each backpacking trial the subject walked for a five minute warm-up period carrying the pack at 2.5 mph (67 m/min) and 0% grade. The pack was then carried at 3.2 mph (86 m/min) for one hour on a Quinton motor-driven treadmill. The treadmill speed and grade were calibrated prior to each load-carrying experiment. The treadmill elevation alternated every 15 minutes from 0% to 3% grade. The load-carrying trials were conducted at least two days apart to minimize a learning effect, and to allow time for the subject to recover.

During both load-carrying trials the subject breathed through a mouthpiece attached to a turbine device. The SensorMedics 4400 metabolic cart was again used for breath-by-breath determination of metabolic and ventilatory variables. Metabolic and ventilatory measurements obtained during load-carrying included oxygen uptake (VO_2), minute ventilation (V_E), and respiratory exchange ratio (R). Heart rate was monitored by leads I, II, III, AVR, AVL, and AVF using a three channel Quinton 4000 Electrocardiograph with oscilloscope. The heart rate during load carrying was determined by dividing 15,000 by the distance (mm) of ten R-R intervals from a reference R-wave.

The ratings of perceived exertion (RPE) according to the original Borg scale (Appendix C) were monitored for chest, shoulder, and leg discomfort. The subject was asked to point to one of the numbers on the scale to indicate her feeling of discomfort for each area. The heart rate and RPE were measured during the last 30 seconds of every five minute interval. The metabolic and ventilatory parameters were measured breath-by-breath and averaged for every 60-second period. The values reported for each five minute interval were an average of the data obtained during the fourth and fifth minutes of that period.

Following each trial the subject was given a short questionnaire (Appendix D) and asked to rate the pack's comfort on shoulder, upper back, lower back, leg, and foot. The subject was also given the opportunity to describe any painful areas. At the end of the second load carrying experiment the subject was asked which of the two packs she would prefer to carry for a prolonged period of time.

Statistical analysis

The data collected were analyzed using a three factor (i.e., pack type, time, grade) repeated measures analysis of variance. The data from the two pack types were compared for each variable within each five-minute interval. Multiple comparisons using Tukeys Honestly Significant Difference procedure were performed on significant F-values to determine which differences were significant. An alpha level of 0.05 was used to establish statistical significance.

The subjective data from the questionnaires were analyzed using the Wilcoxon Matched Pairs Signed-Ranks Test. Again an alpha level of 0.05 was used to establish statistical significance.

IV. RESULTS AND DISCUSSION

Eleven female subjects between 18 and 35 years of age participated in the present study. Each subject was tested on three separate days. The first test session was used to measure body composition by hydrostatic weighing, and to determine the maximal metabolic and cardiorespiratory values achieved during a continuous, multi-stage treadmill test. During the second test session, each subject carried either an internal frame or an external frame backpack loaded with 33% of her body weight. The subject walked at 3.2 mph for 60 minutes with the grade alternating every 15 min (between 0% and 3%). During the third test session, the subject carried the remaining pack under the same conditions as the second test session.

The average absolute weight carried by the subjects was 42.5 lb (19.3 kg) for each pack. The average load carried, relative to lean body weight, was 42.0% for each backpack.

The mean age and anthropometric measurements obtained for the subjects are presented in Tables 1 and 2. The maximum metabolic and cardiorespiratory values obtained during treadmill running are presented in Table 3. The

Table 1. Description of the Subjects

	Age (yr)	Hgt (cm)	Wgt (kg)	Body Fat (%)	Fat wgt (kg)	Lean wgt (kg)
mean	22.4	165.5	58.2	20.7	12.5	45.7
SD	4.3	2.5	8.3	6.8	6.0	3.5

Table 2. Anthropometric Measurements

	Chest cir (cm)	Waist cir (cm)	Hip cir (cm)	Crotch height (cm)	Waist-back length (cm)
mean	87.0	71.3	92.8	78.2	39.8
SD	7.4	7.0	6.3	1.9	1.8

Note: cir is circumference

Table 3. Maximal Oxygen Uptake and Maximum Cardiorespiratory Values Obtained During Incremental Treadmill Exercise

	VO_2max (l/min)	VO_2max (ml/Kg/min)	HRmax (beats/min)	R	V_Emax (l/min)
mean	2.51	43.3	192	1.29	87.0
SD	0.36	6.1	8	0.09	10.7

subjects in the present study were lower in body fat and had a higher mean VO_2max value than the average female soldier of comparable age (Vogel, Patton, Mello, Daniels, 1986.) The average female soldier for this age group has been found to have 28.4% body fat and a VO_2max value of 37.5 ml/kg/min.

Table 4 presents the mean VO_2 values measured every five minutes during the one hour walk for each pack type. During the first 30 min of walking, the oxygen uptake (see Figure 1) values obtained while carrying the internal frame backpack tended to be slightly lower than the values obtained for the external frame pack. However, there were no statistically significant differences found between the two packs. Although VO_2 measures were not

Table 4. Oxygen Uptake Values Obtained While Carrying Internal and External Frame Backpacks

Time (min)	grade (%)	External VO_2 (ml/kg/min)	External $\%VO_2max$	Internal VO_2 (ml/kg/min)	Internal $\%VO_2max$
05	0	17.2 2.3	40.8 10.1	16.8 2.1	39.9 9.7
10	0	16.9 2.3	40.2 10.2	16.3 2.4	38.9 10.2
15	0	16.8 2.4	40.1 10.6	16.8 2.0	39.9 9.6
20	3	20.8 2.2	49.3 11.2	20.3 2.3	48.2 11.5
25	3	20.7 2.6	49.2 12.2	20.2 2.1	48.0 10.9
30	3	21.0 2.2	49.8 11.5	20.6 2.2	48.9 11.8
35	0	16.8 2.6	40.0 10.5	16.8 2.3	40.0 10.0
40	0	16.8 2.6	40.2 11.2	16.9 2.3	40.3 10.3
45	0	17.1 2.4	40.8 10.9	17.0 2.0	40.5 9.9
50	3	20.6 2.6	48.9 12.0	20.5 2.2	48.8 11.5
55	3	20.7 2.5	49.2 12.3	20.6 2.4	48.9 11.9
60	3	20.8 2.6	49.6 12.3	20.7 2.4	49.2 11.8

Note: Values presented are the means ± SD for 11 subjects.

affected by the pack type, they were significantly altered by the treadmill slope as seen in Figure 1. As the

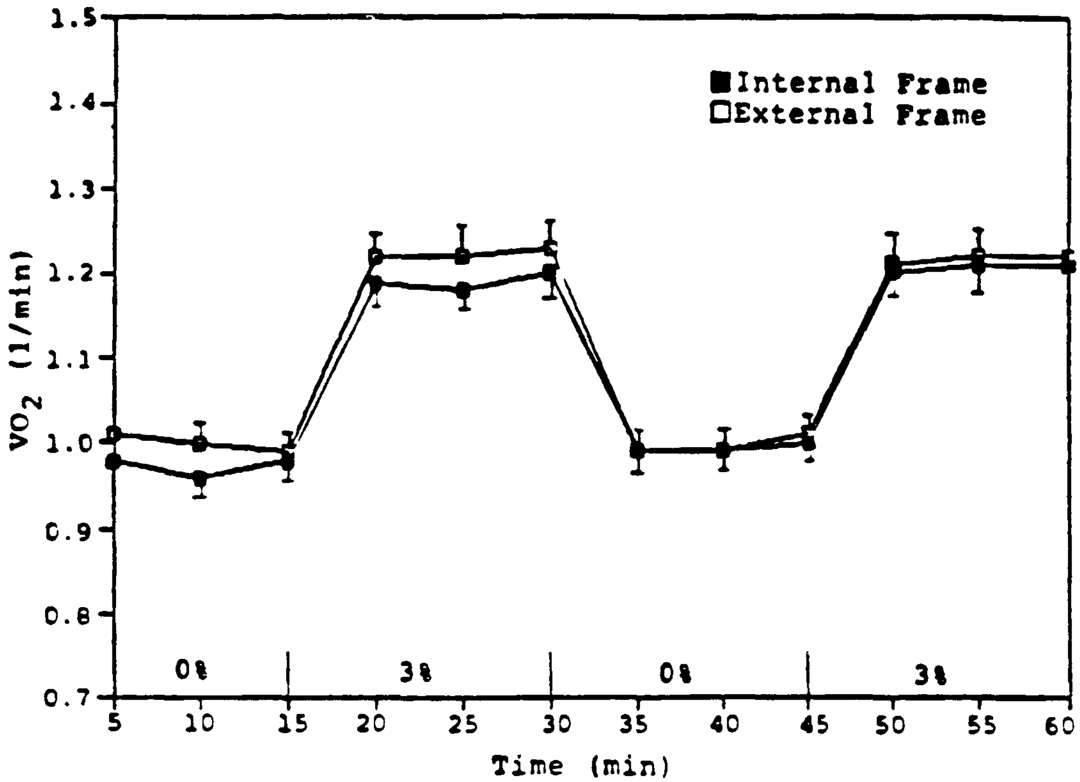

Figure 1. Mean (±SD) Oxygen Uptake Responses of Females Carrying Internal and External Frame Backpacks

treadmill slope was increased from 0 to 3%, oxygen uptake increased significantly. Expressed in METS, an increase in treadmill slope of 3% produced an average increase of 1.1 METS. Exercise duration had no statistically significant effect on VO_2 with either type of pack. In other words, the VO_2 values did not increase as exercise time increased. When VO_2 was expressed as a percentage of VO_2max, the average values were less than 50% for both backpacks under all conditions of speed and grade.

Kcal/min values (determined from oxygen uptake and corresponding R values) were not affected by the type of backpack carried. Regardless of the type of pack carried, grade changes had a significant affect on energy expenditure expressed in kcal/min, while time had no significant affect.

The mean heart rate responses to carrying each type of backpack are presented in Table 5. There were no

Table 5. Heart Rate Values Obtained While Carrying Internal and External Frame Backpacks

Time (min)	Grade (%)	External HR (beats/min)	External %HRmax	Internal HR (beats/min)	Internal %HRmax
05	0	121 22	63.0 11.0	119 25	62.2 12.6
10	0	119 23	61.8 11.4	122 23	63.6 12.2
15	0	118 26	61.5 13.2	121 25	63.3 13.2
20	3	131 24	68.4 11.6	132 27	69.2 14.3
25	3	132 26	69.1 13.4	132 28	69.1 14.6
30	3	132 25	68.7 12.5	135 29	70.6 15.0
35	0	123 25	64.3 12.8	125 27	65.1 13.8
40	0	121 27	63.2 13.8	126 28	65.9 14.3
45	0	122 27	63.4 13.6	124 26	64.6 13.9
50	3	132 27	69.0 14.0	134 28	70.0 14.8
55	3	133 26	69.4 13.3	134 29	70.3 15.5
60	3	133 28	69.5 14.4	137 30	71.3 15.7

Note: Values presented are the mean ± SD for eleven subjects.

significant differences found between the two backpack types for the heart rate measurements observed during exercise. Figure 2 shows the mean heart rate responses obtained while carrying each type of pack. The heart rate responses were sensitive to changes in the slope of the treadmill. There were highly significant differences found in the mean heart rate when comparing 0 and 3% grade. A change in grade from 0 to 3% resulted in an average increase in heart rate of 11 beats/min. The heart rate response was unaffected by exercise time on the treadmill regardless of the type of pack carried.

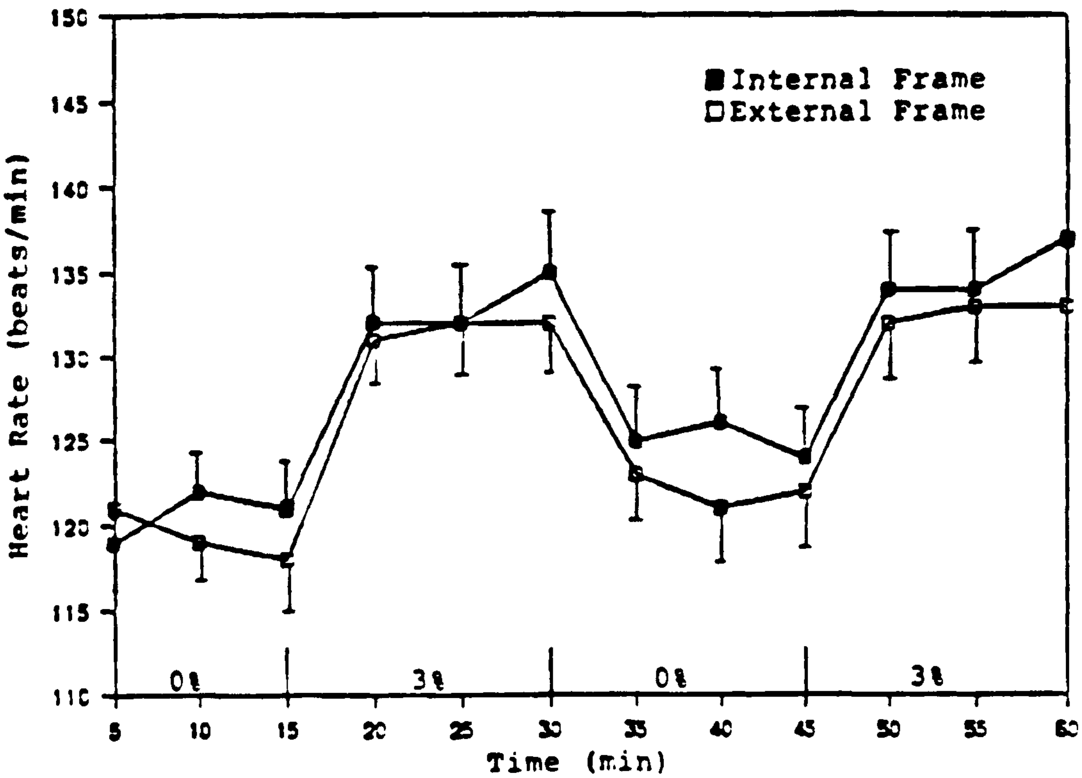

Figure 2. Mean (±SD) Heart Rate Responses of Females Carrying Internal and External Frame Backpacks

The mean values for respiratory exchange ratio for each backpack during the one hour of treadmill walking are provided in Table 6. It was found that backpack type did not significantly influence the R values. However, there was a tendency for R values to be consistently lower with the internal frame than the external frame backpack (see Figure 3).

Table 6. Respiratory Exchange Ratio and Minute Ventilation Values Obtained While Carrying Internal and External Frame Backpacks.

		External		Internal	
Time (min)	Grade (%)	R	V_E (l/min)	R	V_E (l/min)
05	0	0.96	29.4	0.92	27.1
		0.03	6.0	0.05	4.6
10	0	0.96	28.9	0.93	27.6
		0.04	5.6	0.05	5.2
15	0	0.95	28.8	0.93	28.5
		0.03	5.6	0.04	5.1
20	3	0.96	34.3	0.93	32.4
		0.03	6.6	0.04	6.0
25	3	0.96	34.7	0.93	33.0
		0.03	7.1	0.05	6.4
30	3	0.96	35.1	0.94	34.0
		0.03	6.5	0.04	6.1
35	0	0.95	30.3	0.91	29.2
		0.05	5.9	0.05	5.3
40	0	0.92	29.5	0.90	28.9
		0.04	5.5	0.06	6.0
45	0	0.92	30.0	0.90	29.2
		0.04	6.1	0.06	5.1
50	3	0.92	34.4	0.91	33.7
		0.03	6.6	0.04	5.4
55	3	0.93	35.3	0.91	34.0
		0.03	6.6	0.04	6.1
60	3	0.92	35.1	0.92	34.9
		0.04	7.1	0.05	7.0

Note: Values presented are the means ± SD for 11 subjects.

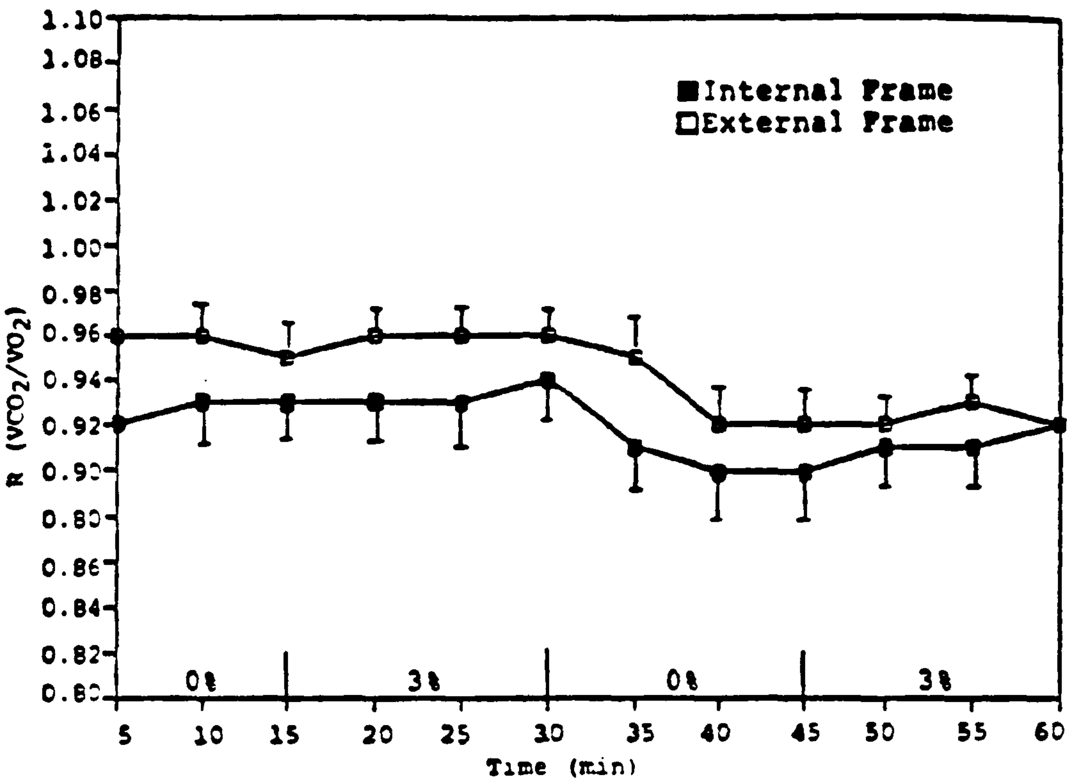

Figure 3. Mean (±SD) Respiratory Exchange Ratio Responses of Females Carrying Internal and External Frame Backpacks

The R values were significantly affected by the grade of the treadmill regardless of the type of backpack carried. Time did not cause any significant changes in the respiratory exchange ratio over the 60 min of exercise.

Minute ventilation values were not significantly altered by the backpack design. The V_E (l/min) values for one hour of treadmill walking for each pack type are shown in Table 6. As illustrated in Figure 4, both the slope of the treadmill and exercise time had a significant influence on the minute ventilation values obtained during exercise. Minute ventilation values significantly increased with increases in treadmill slope and/or time.

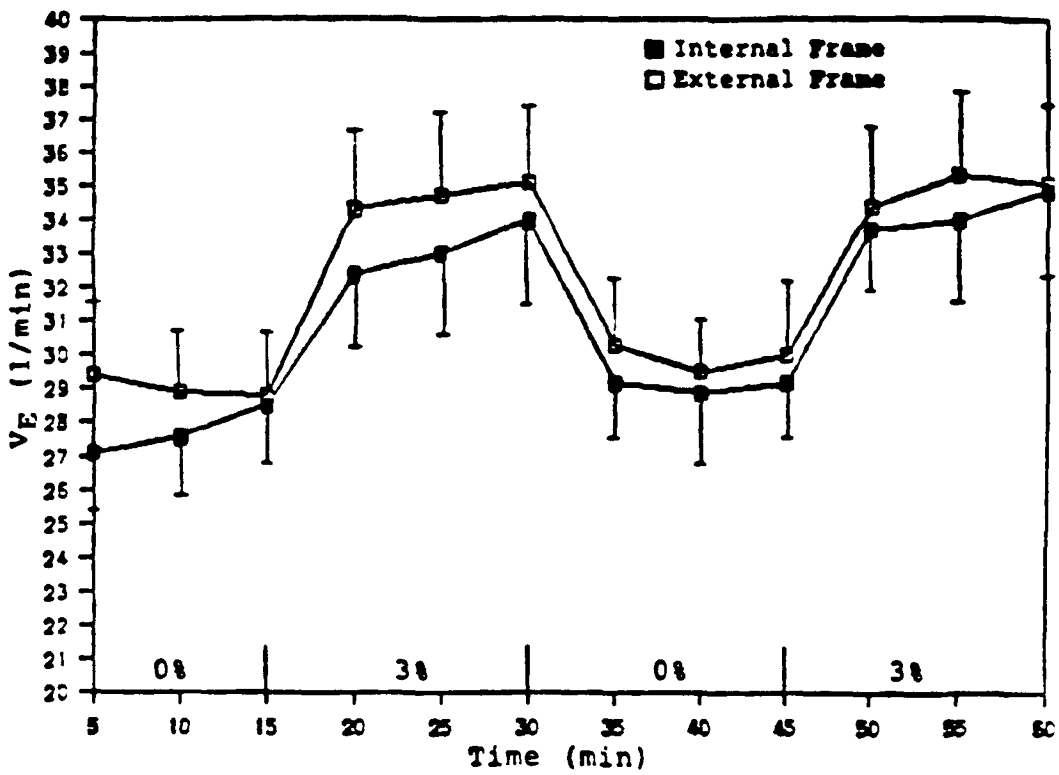

Figure 4. Mean (±SD) Minute Ventilation Responses of Females Carrying Internal and External Frame Backpacks

As the slope of the treadmill changed from 0 to 3%, the average increase in minute ventilation was 5.2 l/min. With regard to exercise time, the minute ventilation values increased an average of 1.0 l/min for both the first 15-min interval compared to the third 15-min interval, and from the second 15-min interval to the fourth 15-min interval.

The type of pack frame carried did not cause any statistically significant differences for the ratings of perceived exertion for either the chest, shoulders or legs. Table 7 presents the RPE values for the chest, shoulders, and legs for both backpacks.

Table 7. Ratings of Perceived Exertion Obtained While Carrying Internal and External Frame Backpacks.

Time (min)	Grade (%)	External Chest	External Shoulders	External Legs	Internal Chest	Internal Shoulders	Internal Leg
05	0	8.6 1.7	10.0 2.8	10.0 2.3	8.2 1.2	8.6 1.2	9.0 1.6
10	0	9.7 2.3	10.8 3.1	10.5 2.5	8.7 1.7	9.7 1.6	9.5 1.7
15	0	10.1 2.1	10.9 2.7	10.7 2.7	9.4 1.4	10.4 1.9	10.4 2.1
20	3	11.2 2.1	11.9 2.7	11.7 2.9	10.5 2.1	11.4 2.1	11.3 2.4
25	3	11.4 1.9	12.3 2.3	12.4 2.6	11.4 1.8	12.0 1.9	12.0 2.8
30	3	11.8 1.5	12.8 2.0	12.6 2.3	11.6 2.0	12.5 2.0	12.0 2.8
35	0	12.0 1.5	13.2 1.9	13.3 2.4	11.6 1.8	13.0 1.9	12.0 2.7
40	0	12.2 1.7	13.6 2.0	13.2 2.2	12.4 2.1	13.3 2.1	12.4 2.9
45	0	12.2 1.7	13.8 1.9	13.1 2.3	12.4 2.1	13.3 2.2	12.6 2.8
50	3	12.6 1.6	14.2 2.2	13.9 2.2	12.8 2.1	13.3 2.2	13.5 2.6
55	3	12.8 1.5	14.4 2.2	14.3 2.0	13.0 2.2	13.8 1.9	13.4 2.8
60	3	12.9 1.8	14.4 2.2	14.4 2.1	13.4 2.4	14.0 2.3	14.0 2.9

Note: Values presented are the means ± SD for 11 subjects

The RPE-chest was significantly effected by time and the slope of the treadmill for the first 30 min of exercise regardless of the pack type carried. However, the second 30 min of exercise resulted in smaller changes in RPE-chest than occurred during the first 30 min of walking. As Figure 5 illustrates, the values reported for RPE-chest started to level off during the second 30 min of exercise, and did not significantly change between 30 and 60 min of exercise.

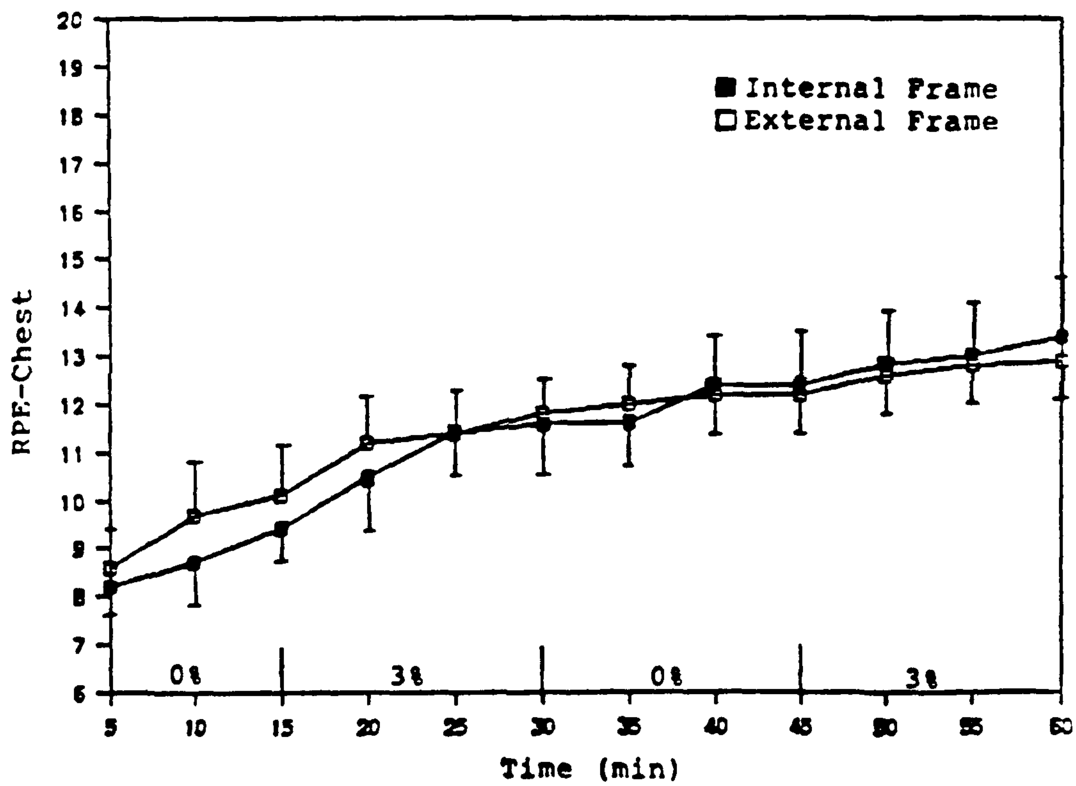

Figure 5. Mean (±SD) Ratings of Perceived Exertion-Chest (RPE-Chest) of Females Carrying Internal and External Frame Backpacks

Regardless of the type of pack frame carried, exercise time caused a significant increase in the RPE-shoulders over the entire hour on the treadmill. Grade increases also caused the RPE-shoulders to significantly increase (see Figure 6).

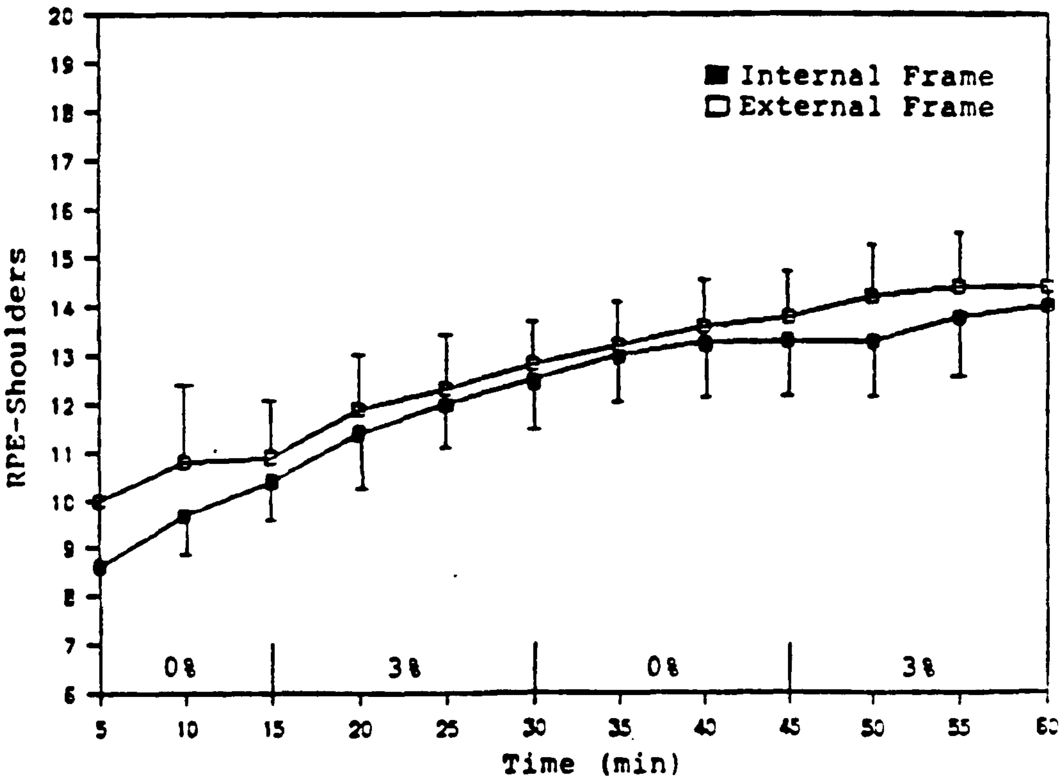

Figure 6. Mean (±SD) Ratings of Perceived Exertion-Shoulders (RPE-Shoulders) for Females Carrying Internal and External Frame Backpacks

Figure 7 shows the values obtained for RPE-legs while carrying each backpack over a 60 minute period. The ratings significantly increased with time, and with changes in the slope of the treadmill, regardless of the type of pack frame the subject carried.

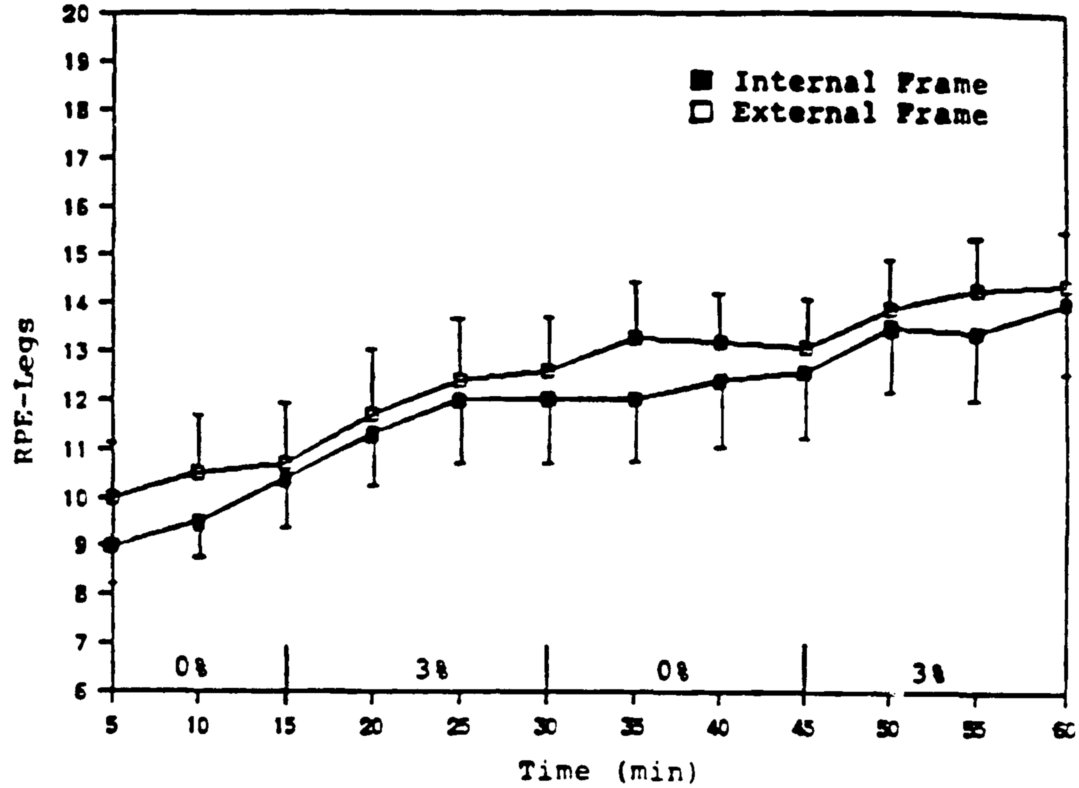

Figure 7. Mean (±SD) Ratings of Perceived Exertion-Legs (RPE-Legs) of Females Carrying Internal and External Frame Backpacks

There were no statistically significant differences found between the two types of backpacks for any of the seven variables measured. However, although not significant, it is interesting to note that subjects carrying the internal frame pack had slightly lower responses for VO_2, R, V_E, RPE-shoulders, and RPE legs than while carrying the external frame pack.

Three subjects worked at an exercise intensity greater than 50% VO_2max for the hour of exercise. The mean values for these three subjects were analyzed separately to determine if the subjects who were working at an exercise intensity above 50% of VO_2max responded differently from the other subjects. It was found that oxygen consumption increased significantly over exercise time, and with changes in the grade regardless of the type of pack carried by these three subjects. It was also found, in subjects exercising above 50% VO_2max, that oxygen consumption was significantly lower while carrying the internal frame pack than while carrying the external frame pack. The RPE-legs were significantly lower when carrying the external frame pack than when carrying the internal frame pack. Also, each of these three subjects indicated that they preferred carrying the external frame pack compared to the internal frame pack. These inconsistent results cannot be logically explained, and are likely due to the small number of subjects analyzed. The other five variables measured in these three subjects produced results that were similar to those obtained for the entire group.

At the end of the second load-carrying trial, each of the 11 subjects were asked to indicate which of the two packs they preferred to carry. Six indicated they preferred the external frame pack, and five indicated they preferred the internal frame pack.

The subjects were also asked to complete a questionnaire (Appendix D) at the end of each load carrying trial to investigate any possible painful areas of the body that occurred during the load carrying task. The questionnaire asked the subjects to rate the degree of discomfort they experienced while carrying each pack for the following anatomical areas: shoulders, back, hips, knees, ankles, and feet. The questionnaire also compared the overall comfort rating the subjects reported for each pack. The results showed no statistically significant differences between the two packs for any of the subjective data collected by the questionnaires.

Discussion

The primary objective of the present study was to determine if differences exist between the metabolic, cardiorespiratory, or perceptual responses of subjects carrying U.S. Army internal and external frame backpacks. Several past studies have investigated the effects of different load-carrying modes in male participants, but little research has been conducted in this area on female subjects.

The present study examined female subjects only. The results showed that oxygen consumption, heart rate, minute ventilation, respiratory exchange ratio, and the ratings of perceived exertion for the chest, shoulders and legs were not significantly affected by the type of backpack carried. This agrees with recent work of Patton et al. (1990), who found no significant differences in VO_2, HR, V_E, and RPE, for male subjects carrying U.S. Army Internal and External Frame backpacks. Winsmann and Goldman (1976) reported similar results in that the specific design of a backpack (i.e., with or without a waiststrap) did not have a significant influence on energy costs in male subjects. However, the packs studied by Winsmann and Goldman only differed in respect to whether or not they had a waiststrap. The present study examined packs that had entirely different suspension systems and found results similar to those of Winsmann and Goldman.

Legg and Mahanty (1985) also found no statistically significant differences in the energy costs of five modes of carrying a load close to the trunk in male subjects. However, they found statistically significant differences in the subjective ratings of the modes of load carrying employed. In the present study, there were no significant differences in the RPE values measured in subjects carrying internal or external frame backpacks. Legg and Mahanty may have discovered perceptual differences because they compared load carrying methods that distributed the load over the body more than the modes employed in the present study.

Bloom and Woodhull-McNeal (1987) were also able to detect differences in the subjective ratings of individuals wearing commercial internal and external frame backpacks. However, Bloom and Woodhull-McNeal collected subjective data on subjects who were wearing the backpacks while standing in one place. The present investigation obtained subjective measures from dynamic exercise over a prolonged period of time, and compared two different backpacks than those studied by Bloom and Woodhull-McNeal.

The subjective data of the present study were evenly divided regarding the type of pack the subject would prefer to wear. However, individual discussions with the subjects indicated that if the external frame pack was padded as much as the internal frame pack, more of the subjects may have chosen the external frame because it was not as cumbersome on their backs.

It is of particular interest that the RPE for the chest, shoulders, and legs increased with exercise time, while oxygen consumption, respiratory exchange ratio, and heart rate were not affected by exercise time. For the chest, RPE rose significantly for the first 30 min and then leveled off. For the shoulders and legs, the RPE values continued to rise over the entire 60 min of exercise. The increase in RPE with exercise duration may have been a result of increasing local fatigue in the assessed areas which could be mentally detected by the subjects, but was not great enough to influence energy cost. In other words, the exertion perceived by the subjects for the load carrying activity over exercise time was greater than the physiological data would indicate. The RPE values may have also been influenced by the subject's mental fatigue due to concentrating on the load-carrying exercise for one h.

In the present study, a 3% rise in treadmill grade resulted in an average MET increase of 1.1 METS, and caused oxygen consumption, respiratory exchange ratio, minute ventilation, heart rate and RPE to rise significantly. This indicates that when carrying a heavy load even small increases in grade are mentally and physiologically stressful.

In the present study, the significant increase in minute ventilation with exercise time was possibly a response to a rise in core body temperature (Kalis, Freund, Joyner, Silka, Nittolo, and Wilmore, 1988). However, body temperature measures were not monitored in the present study. The increase in minute ventilation with exercise time may also have been due to apprehension about the increasingly more difficult load carrying task as subjectively reported through the RPE measures.

In contrast to the current findings, previous studies have found significant differences in energy cost between various modes of load carrying (Soule & Goldman (1969), Datta & Ramanathan (1971)). However, the above studies compared modes of load carrying that were greatly different from one another. The modes of load carrying examined in the above studies utilized various muscle groups. In the present study both loads were placed on the back. Therefore, similar muscle groups were involved in carrying each type of backpack and this resulted in similar metabolic, cardiorespiratory, and perceptual responses to exercise.

In a recent study by Epstien, Rosenblum, Burstien and Sawka (1988), it was found that when exercise intensity was below 50% of VO_2max energy cost remained constant for a 2 hour duration. When work intensity reached 50% of VO_2max, energy cost increased with time over a 2 hour period. The data from the present study showed that energy cost remained constant over the 1 hour exercise period, but increased with an increase in grade. The average intensity of work in the present study never increased above 49% VO_2max, and exercise time did not have a significant effect on energy cost. Three subjects in the present study worked at levels of exercise intensity greater than 50% VO_2max during the hour of walking. The data obtained from these three subjects showed that oxygen consumption increased significantly with exercise time. This agrees with the work of Epstien et al. who suggested that this increase in energy cost may be a result of the altered biomechanics of carrying a heavy load that results in an oxygen uptake of greater than 50% VO_2max.

Based on the conclusions of Epstien et al., a heavier load, faster walking speed, and/or increase in grade may have caused the mean VO_2 of all 11 subjects to increase with time in the present study. Furthermore, the mean oxygen consumption for the three subjects who exercised at greater than 50% VO_2max in the present study was significantly lower when carrying the internal frame pack than when carrying the external frame pack. This difference in oxygen consumption was not detected in the mean value for all eleven subjects.

It is interesting to note the responses of oxygen consumption, respiratory exchange ratio, minute ventilation, heart rate, and RPE of the chest, shoulders, and legs to increases in treadmill grade. As seen in Figures 1-7, these variables were greatly influenced by an increase in the treadmill slope as small as 3%. From these data it is apparent that as long as the speed of walking remains constant, small increases in the slope of the terrain will greatly increase the difficulty of load carrying.

The results from the present study showed that their are no statistically significant differences in the mean metabolic or perceptual responses of female subjects carrying a U.S. Army internal or external frame backpack loaded with 33% of their body weight. Differences may exist if the packs are loaded excessively due to the differences in the rigidity of the two types of frames. It is a common belief among backpackers that an excessively heavy load in an internal frame backpack will shift more, and cause an unbalanced load, than an excessively heavy load in an external frame pack.

Differences in certain biomechanical parameters may exist in subjects carrying the two types of backpacks that are more easily detected than metabolic data. It was suggested by Martin (1985) that the increased physiological demands of carrying heavier loads is directly related to mechanical work increases. Therefore, when evaluating load carrying systems investigators should measure metabolic, cardiorespiratory, perceptual, and biomechanical responses to determine if any subtle differences may exist that cannot be detected through metabolic and cardiorespiratory data alone.

V. CONCLUSIONS, RECOMMENDATIONS

Conclusions

It was concluded that no differences exist in the metabolic, cardiorespiratory or perceptual responses of females carrying either an internal or external frame backpack loaded with 33% of their body weight. This indicates that as long as the load is carried on the back, differences in backpack frame designs are not great enough to produce significant differences in the energy cost or perception of carrying a moderate load. It may be that the most important aspects of backpack design are the padding, fit and general comfort rather than the specific frame type.

Regardless of the type of pack worn, it was also concluded that small increases in the slope of the terrain (in subjects walking at constant speeds) will result in highly significant increases in energy cost, and the perception of exertion.

Recommendations for Further Study

Efforts to evaluate load carrying methods have been incomplete. It is still to be determined how differences in backpack designs can be measured, if at all. Further comparisons of the two types of backpacks should be conducted on females involving loads that result in oxygen costs greater than 50% VO_2max. Studies should also be conducted on females walking on uneven or downhill terrain. Furthermore, biomechanical data should also be included in comparing the two types of backpacks both in men and women so that possible biomechanical differences do not go unnoticed.

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APPENDIX A

INFORMED CONSENT

NORTHEASTERN UNIVERSITY
360 Huntington Avenue
Boston, Massachusetts 02115

Office of Environmental Health and Safety
(617) 437-2147 or 2769

HUMAN SUBJECTS COMMITTEE

INFORMED CONSENT

Subject's Name: ________________________________ Date _____

Project Director: Donald Schneider, Ph.D. and John Kirk
437-2526

Project Title: The metabolic costs of prolonged load carrying in women using internal and external frame backpacks.

DESCRIPTION AND EXPLANATION OF PROCEDURES

Many women carry backpacks in military and recreational settings. However, very little research has been conducted involving the loads women carry. Research indicates that different methods of load carrying demand different energy costs. It has not been well examined if design differences in backpacks will result in different energy costs in an individual when carrying the same load in each pack. We would like to see if there is a difference of energy cost in individuals when carrying U.S. Army internal and an external frame backpacks.

Test Procedures:

At least ten healthy female volunteers between the ages of 18-35 years of age will serve as subjects for this study. On the first day of testing each participant will be asked to perform a graded maximimal exercise stress test. This will involve a continuous incremental test on a motor driven treadmill. The exercise will begin at a very low intensity and will increase by a small amount every three minutes until you can no longer exercise. You will also be weighed underwater to determine the percentage of your body which is lean tissue and which is fat tissue.

There will be two more test sessions on separate days. Each time you will be asked to walk on a treadmill for one hour at 3.2 mph while carrying a backpack loaded with 33% of your body weight. The grade of the treadmill will alternate every fifteen minutes from 0% to 3%.

Expired gas will be gathered and analyzed during the last minute of every five minute interval. Heart rate will be continuously monitored through a single lead electrocardiogram (two electrodes placed on the chest). You will also be asked to answer a short questionaire regarding backpack comfort following each load bearing trial.

RISKS AND DISCOMFORTS

Although unlikely, it is possible that you may run the risk of certain discomforts during the testing. Discomforts due to the physical exertion might include: fatigue, distress, irritation, anxiety, pain in the side, breathlessness, light headedness, dizziness, faintness, nausea, weakness, muscle cramps, blisters, pain in the legs, feet, shoulders or back, or an "unwell" feeling. There also exists the possibility of certain changes occuring during the exercise tests. They include abnormal blood pressure responses, fainting, heart beat disorders, and in rare instances, heart attack. In a small number of people there exists an uncomfortable feeling with being underwater. These people may experience discomfort with expelling all the air in their lungs while being weighed underwater.

You are reminded that it is your right to stop or withdraw from this procedure at any time and for any reason you deem necessary.

POTENTIAL BENEFITS

The results from the underwater weighing will provide you with information regarding what percentage of your body is fat, and what percentage is lean tissue.

The results from the maximal exercise test will provide an assessment of your physiological responses to submaximal and maximal levels of exercise stress. The exercise test results will be presented to each participant, and will include such information as maximal aerobic capacity and the heart rate response at each level of exercise intensity. These are considered to be two excellent indexes of cardiovascular fitness. The data collected may also be of benefit to those participants who are interested in backpacking, by helping them decide the type of backpack which is best suited for them.

ALTERNATIVES

The only alternative to any of the methods described above, would be to use skinfold calipers in lieu of hydrostatic weighing to determine body composition. However, skinfold calipers are known to be inaccurate, and unreliable from one technician to the next.

CONSENT

The following statement is included in compliance with federal government regulations.

> I understand that in the unlikely event physical injury occurs resulting from the research procedure, medical treatment will be available at Northeastern University or another appropriate health facility. However, no special arrangements will be made for compensation or for payment for treatment soley because of my participation in this research.

I have fully explained to________________________________
subject/parent/guardian
the nature and purpose of the above-described procedure and the risks that are involved in its performance. I have answered and will answer all questions to the best of my ability.

____
Project Director's Signature

I have been fully informed of the above-described procedure with its possible benefits and risks. I give permission for me/my child's participation in this study. I know that Dr. Don Schneider or his associates will be available to answer any questions I may have. I understand that I am free to withdraw this consent and discontinue participation in this project at any time without its affecting me/my child's care. I have received a copy of this form.

____
Signature of subject/parent/guardian

____
Witness to signatures

APPENDIX B

BRUCE PROTOCOL

BRUCE PROTOCOL

Stage	Duration (min)	Speed (mph)	Treadmill grade(%)
1	3	1.7	10
2	3	2.5	12
3	3	3.4	14
4	3	4.2	16
5	3	5.0	18
6	3	5.5	20
7	3	6.0	22

APPENDIX C

BORG SCALE

BORG SCALE

6	
7	VERY VERY LIGHT
8	
9	VERY LIGHT
10	
11	LIGHT
12	
13	MODERATE
14	
15	HEAVY
16	
17	VERY HEAVY
18	
19	VERY VERY HEAVY
20	

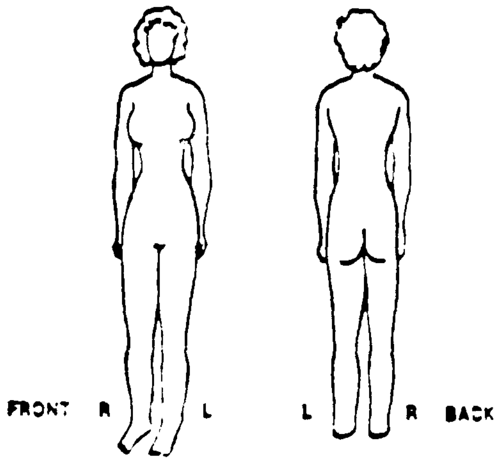
APPENDIX D

QUESTIONNAIRE

NAME________________________ DATE__________

1. Please rate any discomfort that you may have felt on each of the listed sites on your body. Please answer each of the questions using the following scale, and mark the exact spot on the figure.

no discomfort	slightly uncomfortable	moderately uncomfortable	very uncomfortable	extremely uncomfortable
0	1	2	3	4



a) Discomfort on your shoulders_______.
b) Discomfort of your back_______.
c) Discomfort of your hips______.
d) Discomfort of your knees______.
e) Discomfort of your ankles_______.
f) Discomfort of your feet (not including blisters)_______.

g) Please identify any other areas of discomfort and rate it on the scale.
Area(s)1.__________2.________3.________rating 1._____2.______3.______

PLEASE ANSWER THE FOLLOWING QUESTIONS BRIEFLY IN THE SPACE PROVIDED.

j) Did you get blisters on your feet from walking on the treadmill today?
____

k) Have you ever been backpacking, or worn a large backpack for an extended period of time before participating in this study_________.

l) How would you rate the overall comfort of this pack using the following scale.

very uncomfortable	somewhat uncomfortable	neither comfortable nor uncomfortable	somewhat comfortable	very comfortable
1	2	3	4	5

APPENDIX E

INDIVIDUAL SUBJECT DATA

Subject # 1
Internal Frame
Pack Weight: 45.00 lb
% Lean Body Weight: 43.6

Age: 25
Height: 168.1 cm
Weight: 62.1 kg
% Body Fat: 24.6

min	VO_2 l/min	%VO_2 max	V_E l/min	R
05	1.16	45.9	31.5	0.88
10	1.21	48.0	33.0	0.90
15	1.23	48.8	35.0	0.90
20	1.51	59.9	43.0	0.95
25	1.53	60.8	45.0	0.94
30	1.49	59.1	45.0	0.96
35	1.26	50.0	38.5	0.88
40	1.31	51.8	39.5	0.88
45	1.25	49.6	37.5	0.88
50	1.48	58.9	44.0	0.90
55	1.47	58.3	44.5	0.90
60	1.54	61.1	47.5	0.90

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.4	46.1	144	75.4	09	09	09
10	5.6	48.3	146	76.4	09	11	11
15	5.7	49.3	155	81.2	11	13	13
20	6.9	59.5	165	86.4	14	14	14
25	7.0	60.8	170	89.0	15	15	16
30	6.9	59.5	172	90.1	15	15	16
35	5.8	50.0	163	85.3	15	15	17
40	6.0	52.2	163	85.3	17	17	18
45	5.8	49.6	161	84.3	17	17	17
50	6.8	58.6	174	91.1	17	17	18
55	6.8	58.2	174	91.1	17	17	18
60	7.1	61.2	179	93.7	19	19	19

Subject # 1
External Frame
Pack Weight: 45.00 lb
% Lean Body Weight: 43.6

Age: 25
Height: 168.1 cm
Weight: 62.4 kg
% Body Fat: 24.6

min	VO_2 l/min	$\%VO_2$ max	V_E l/min	R
05	1.27	50.0	35.0	0.94
10	1.30	51.2	36.0	0.94
15	1.27	50.1	36.0	0.94
20	1.51	59.6	43.0	0.97
25	1.51	59.5	42.5	0.94
30	1.51	59.7	41.5	0.93
35	1.24	48.9	37.5	0.90
40	1.28	50.7	36.0	0.88
45	1.30	51.5	38.0	0.90
50	1.60	63.1	44.0	0.90
55	1.49	58.6	43.0	0.92
60	1.61	63.5	44.5	0.90

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.8	50.0	152	79.6	11	13	13
10	6.0	51.3	152	79.6	13	13	13
15	5.8	50.0	158	82.7	13	13	14
20	6.9	59.5	166	86.9	14	15	15
25	6.9	59.5	172	90.1	14	14	14
30	7.0	59.9	169	88.5	14	14	14
35	5.6	48.7	161	84.3	15	15	15
40	5.8	50.4	161	84.3	15	15	15
45	6.0	51.3	163	85.3	15	15	15
50	7.3	62.9	179	93.7	16	16	16
55	6.8	58.6	172	90.1	16	16	16
60	7.4	63.4	179	93.7	16	16	16

Subject # 2
Internal Frame
Pack Weight: 44.00 lb
% Lean Body Weight: 38.0

Age: 18
Height: 166.1 cm
Weight: 60.6 kg
% Body Fat: 14.1

min	VO_2 l/min	%VO_2 max	V_E l/min	R
05	1.00	42.3	27.0	0.90
10	1.07	43.3	27.5	0.89
15	1.10	44.5	30.5	0.91
20	1.29	52.2	31.0	0.88
25	1.23	49.5	29.5	0.90
30	1.21	48.9	31.0	0.90
35	1.10	44.2	27.0	0.86
40	1.07	43.3	28.0	0.90
45	1.13	45.5	29.0	0.86
50	1.24	50.2	32.0	0.87
55	1.32	53.3	31.0	0.88
60	1.28	51.6	31.5	0.88

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.0	42.7	122	69.3	09	10	11
10	5.1	43.6	132	75.0	11	11	12
15	5.2	44.9	128	72.7	10	11	13
20	6.1	52.1	149	84.7	11	11	13
25	5.8	49.6	147	83.5	11	11	14
30	5.8	49.1	146	83.0	12	13	13
35	5.2	44.4	136	77.3	11	14	13
40	5.1	43.6	135	76.7	12	14	13
45	5.4	45.7	136	77.3	12	14	13
50	5.9	50.4	140	79.5	12	13	15
55	6.3	53.8	146	83.0	13	14	14
60	6.0	51.7	146	83.0	13	13	14

Subject # 2
External Frame
Pack Weight: 44.00 lb
% Lean Body Weight: 37.9

Age: 18
Height: 166.1 cm
Weight: 60.3 kg
% Body Fat: 14.1

min	VO_2 l/min	%VO_2 max	V_E l/min	R
05	0.96	38.6	24.0	0.90
10	1.01	40.6	25.0	0.91
15	1.08	43.6	28.5	0.91
20	1.21	48.8	29.5	0.94
25	1.21	48.8	31.0	0.94
30	1.20	48.4	30.0	0.94
35	1.00	40.5	26.0	0.92
40	1.02	41.1	26.5	0.89
45	1.03	41.4	27.5	0.89
50	1.21	48.8	29.5	0.90
55	1.24	49.8	32.5	0.92
60	1.24	49.9	49.9	0.90

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	4.5	38.5	115	63.3	10	13	11
10	4.8	40.6	115	63.3	11	13	11
15	5.1	43.6	118	67.0	11	13	12
20	5.8	49.1	129	73.3	12	13	13
25	5.8	49.1	133	75.6	12	13	14
30	5.7	48.7	128	72.7	12	14	14
35	4.8	40.6	123	69.9	11	13	13
40	4.8	41.5	123	69.9	11	14	13
45	4.8	41.5	119	67.6	11	13	12
50	5.7	48.7	135	76.7	11	13	14
55	5.8	50.0	139	79.0	11	13	14
60	5.8	50.0	139	79.0	11	13	13

min	VO_2 l/min	% VO_2 max	V_E l/min	R
05	0.98	34.7	24.5	0.84
10	0.95	33.8	27.0	0.91
15	0.94	33.2	26.5	0.88
20	1.14	40.5	32.5	0.92
25	1.22	43.2	30.5	0.87
30	1.20	42.5	33.0	0.92
35	1.04	37.0	28.5	0.90
40	1.00	35.3	28.0	0.88
45	0.97	34.5	26.5	0.86
50	1.19	42.2	31.5	0.88
55	1.17	41.6	33.0	0.90
60	1.18	42.0	32.0	0.88

Subject # 3
Internal Frame
Pack Weight: 43.40 lb
% Lean Body Weight: 44.6

Age: 21
Height: 167 cm
Weight: 59.6 kg
% Body Fat: 23.9

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	4.6	34.4	115	61.2	07	07	08
10	4.6	33.7	122	64.9	07	07	08
15	4.5	33.3	114	60.6	08	08	09
20	5.5	40.7	123	65.4	09	08	10
25	5.8	43.3	120	63.8	11	10	10
30	5.8	42.6	122	64.9	12	10	11
35	5.0	37.0	107	56.9	12	10	12
40	4.8	35.6	108	57.4	13	10	13
45	4.6	34.4	109	58.0	13	11	14
50	5.7	42.2	117	62.2	13	11	15
55	5.6	41.5	115	61.2	13	12	15
60	5.6	41.9	116	61.7	13	12	16

Subject # 3
External Frame
Pack Weight: 42.50 lb
% Lean Body Weight: 43.7

Age: 21
Height: 167 cm
Weight: 58.4 kg
% Body Fat: 23.9

min	VO_2 l/min	$\%VO_2$ max	V_E l/min	R
05	1.03	37.2	31.5	0.99
10	0.98	35.6	26.5	0.90
15	0.89	32.2	26.0	0.94
20	1.14	41.4	29.0	0.90
25	1.14	41.1	28.5	0.90
30	1.14	41.3	31.5	0.92
35	0.90	32.7	26.0	0.90
40	0.85	31.0	25.0	0.90
45	0.92	33.2	24.5	0.86
50	1.13	40.9	31.0	0.89
55	1.10	40.1	31.0	0.90
60	1.14	41.3	29.0	0.88

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.0	37.0	111	59.0	07	08	08
10	4.8	35.6	103	54.8	08	07	08
15	4.4	32.2	103	54.8	08	07	07
20	5.6	41.5	116	61.7	09	08	07
25	5.6	41.5	114	60.6	10	08	09
30	5.6	41.5	116	61.7	11	10	09
35	4.4	32.6	103	54.8	12	10	11
40	4.2	31.1	106	56.4	13	12	11
45	4.5	33.3	103	54.8	12	11	11
50	5.6	41.1	115	61.2	13	12	12
55	5.4	40.0	112	59.6	14	12	13
60	5.6	41.5	115	61.2	14	13	12

Subject # 4
Internal Frame
Pack Weight: 35.00 lb
% Lean Body Weight: 38.9

Age: 18
Height: 162.5 cm
Weight: 47.6 kg
% Body Fat: 14.4

min	VO_2 l/min	%VO_2 max	V_E l/min	R
05	0.89	57.5	23.5	0.90
10	0.88	57.1	23.5	0.88
15	0.88	57.1	23.0	0.87
20	1.07	69.8	29.5	0.92
25	1.07	69.3	28.5	0.90
30	1.10	71.4	30.5	0.92
35	0.88	57.3	24.5	0.84
40	0.91	59.3	22.5	0.84
45	0.88	57.4	23.0	0.84
50	1.08	70.1	28.0	0.88
55	1.06	69.2	28.5	0.88
60	1.09	71.0	29.0	0.88

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.3	57.6	151	76.6	08	08	09
10	5.2	57.1	146	74.1	08	10	10
15	5.2	57.1	152	77.2	10	10	10
20	6.4	70.1	166	84.3	12	11	13
25	6.4	69.6	169	85.8	13	14	15
30	6.6	71.2	173	87.8	13	14	15
35	5.3	57.6	153	77.7	13	14	13
40	5.4	59.2	159	80.7	14	15	14
45	5.3	57.6	154	78.2	14	15	15
50	6.5	70.7	172	87.3	15	14	16
55	6.4	69.6	172	87.3	16	15	17
60	6.6	71.2	172	87.3	16	15	18

Subject # 4
External Frame
Pack Weight: 36.25 lb
% Lean Body Weight: 40.0

Age: 18
Height: 162.5 cm
Weight: 49.6 kg
% Body Fat: 14.4

min	VO_2 l/min	$\%VO_2$ max	V_E l/min	R
05	0.87	54.3	23.0	0.94
10	0.86	53.6	23.5	0.97
15	0.89	55.9	24.0	0.94
20	1.05	65.5	29.5	1.00
25	1.08	67.5	30.0	0.98
30	1.07	67.0	30.0	0.97
35	0.89	56.0	24.5	0.93
40	0.91	57.1	25.0	0.92
45	0.92	57.3	24.0	0.92
50	1.04	65.2	28.5	0.96
55	1.09	68.4	30.5	0.95
60	1.08	67.5	30.0	0.95

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.0	54.3	142	72.1	08	08	09
10	5.0	53.8	143	72.6	09	10	10
15	5.2	56.0	144	73.1	10	11	10
20	6.0	65.8	158	80.2	12	12	12
25	6.2	67.9	165	83.8	12	11	13
30	6.2	67.4	166	84.3	12	12	13
35	5.2	56.5	149	75.6	12	13	13
40	5.2	57.1	150	76.1	12	14	13
45	5.3	57.6	152	77.2	12	14	13
50	6.0	65.2	161	81.7	13	13	15
55	6.3	68.5	166	84.3	13	13	15
60	6.2	67.4	165	83.8	14	14	16

Subject # 5
Internal Frame
Pack Weight: 36.20 lb
% Lean Body Weight: 37.7

Age: 22
Height: 164.1 cm
Weight: 49.7 kg
% Body Fat: 11.4

min	VO_2 l/min	$\%VO_2$ max	V_E l/min	R
05	0.68	28.8	21.0	0.88
10	0.68	28.7	22.5	0.92
15	0.70	29.2	24.0	0.92
20	0.88	37.1	26.5	0.89
25	0.88	37.2	28.0	0.89
30	0.90	37.9	28.0	0.88
35	0.68	28.5	24.0	0.88
40	0.71	30.0	24.0	0.86
45	0.70	29.3	25.0	0.86
50	0.86	36.0	27.5	0.88
55	0.88	37.1	29.0	0.88
60	0.86	36.1	29.5	0.90

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	4.0	28.8	115	56.7	11	11	11
10	3.9	28.5	115	56.7	11	11	11
15	4.0	29.2	124	61.1	11	11	11
20	5.0	36.9	127	62.6	11	11	11
25	5.1	37.2	126	62.1	11	11	11
30	5.2	37.6	134	66.0	11	11	12
35	3.9	28.5	126	62.1	11	11	11
40	4.1	29.9	120	59.1	11	11	11
45	4.0	29.2	122	60.0	11	11	12
50	5.0	36.1	132	65.0	12	11	13
55	5.0	36.9	127	62.6	11	12	13
60	5.0	36.1	133	65.5	11	12	13

Subject # 5
External Frame
Pack Weight: 36.30 lb
% Lean Body Weight: 37.8

Age: 22
Height: 164.1 cm
Weight: 49.8 kg
% Body Fat: 11.4

min	VO_2 l/min	$\%VO_2$ max	V_E l/min	R
05	0.68	28.8	21.0	0.88
10	0.68	28.7	22.5	0.92
15	0.70	29.2	24.0	0.92
20	0.88	37.1	26.5	0.89
25	0.88	37.2	28.0	0.89
30	0.90	37.9	28.0	0.88
35	0.68	28.5	24.0	0.88
40	0.71	30.0	24.0	0.86
45	0.70	29.3	25.0	0.86
50	0.86	36.0	27.5	0.88
55	0.88	37.1	29.0	0.88
60	0.86	36.1	29.5	0.90

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	4.0	28.8	115	56.7	11	11	11
10	3.9	28.5	115	56.7	11	11	11
15	4.0	29.2	124	61.1	11	11	11
20	5.0	36.5	127	62.6	11	11	11
25	5.1	37.2	126	62.1	11	11	11
30	5.2	37.6	134	66.0	11	11	12
35	3.9	28.5	126	62.1	11	11	11
40	4.1	29.9	120	59.1	11	11	11
45	4.0	29.2	122	60.0	11	11	12
50	5.0	36.1	132	65.0	12	11	13
55	5.0	36.9	127	62.6	11	12	13
60	5.0	36.1	133	65.5	11	12	13

Subject # 6
Internal Frame
Pack Weight: 36.30 lb
% Lean Body Weight: 40.2

Age: 22
Height: 167.7 cm
Weight: 50.0 kg
% Body Fat: 17.4

min	VO_2 l/min	$\%VO_2$ max	V_E l/min	R
05	0.83	32.6	23.5	0.95
10	0.77	29.9	22.0	0.99
15	0.79	30.6	21.5	0.97
20	0.97	37.8	25.5	0.98
25	0.94	36.7	26.5	1.00
30	0.95	37.1	26.5	0.99
35	0.80	31.3	23.0	0.95
40	0.80	31.0	22.0	0.96
45	0.82	32.0	24.5	0.96
50	1.01	39.5	29.0	0.96
55	0.97	37.8	28.0	0.96
60	1.01	39.5	28.0	0.96

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	4.8	32.6	83	42.1	07	07	06
10	4.4	29.9	83	42.1	07	07	07
15	4.5	30.6	82	41.6	07	07	07
20	5.6	37.8	90	45.7	07	09	07
25	5.4	36.7	92	46.7	09	09	07
30	5.4	37.1	95	48.2	09	10	07
35	4.6	31.3	85	43.1	09	11	07
40	4.6	31.0	84	42.6	11	11	07
45	4.7	32.0	84	42.6	11	11	07
50	5.8	39.5	96	48.7	11	12	09
55	5.6	37.8	97	49.2	12	12	09
60	5.8	39.5	98	49.7	12	12	09

Subject # 6
External Frame
Pack Weight: 36.20 lb
% Lean Body Weight: 40.0

Age: 22
Height: 167.1 cm
Weight: 49.8 kg
% Body Fat: 17.4

min	VO_2 l/min	%VO_2 max	V_E l/min	R
05	0.85	33.1	23.5	0.96
10	0.82	31.9	24.5	1.04
15	0.82	32.0	22.0	1.00
20	1.01	39.5	25.5	0.98
25	0.95	37.2	25.0	0.98
30	1.03	40.1	27.5	0.98
35	0.80	31.2	25.5	1.02
40	0.81	31.6	23.0	0.97
45	0.79	30.6	23.0	0.96
50	0.98	38.4	26.0	0.94
55	0.94	36.8	26.5	0.99
60	0.93	36.4	26.5	0.99

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	4.9	33.3	97	49.2	06	06	06
10	4.7	32.0	97	49.2	06	06	06
15	4.8	32.3	97	49.2	06	06	06
20	5.8	40.0	112	56.8	07	07	07
25	5.5	37.4	105	53.3	07	09	07
30	5.9	40.1	114	57.9	09	09	08
35	4.6	31.3	98	49.7	09	11	09
40	4.6	31.6	94	47.7	09	10	09
45	4.6	31.0	99	50.3	09	11	09
50	5.6	38.4	106	53.8	10	12	10
55	5.4	37.1	106	53.8	11	12	11
60	5.4	36.4	106	53.8	11	12	11

Subject # 7
Internal Frame
Pack Weight: 43.00 lb
% Lean Body Weight: 42.6

Age: 21
Height: 162.2 cm
Weight: 59.0 kg
% Body Fat: 20.7

min	VO_2 l/min	$\%VO_2$ max	V_E l/min	R
05	0.96	32.6	30.0	0.95
10	0.98	33.3	30.5	0.96
15	0.96	32.7	31.5	1.00
20	1.20	41.0	35.0	0.94
25	1.18	40.0	33.5	0.96
30	1.18	40.3	37.0	0.99
35	0.97	33.1	32.0	0.99
40	1.00	34.2	34.0	1.00
45	0.97	33.0	32.0	0.98
50	1.16	39.7	35.5	0.96
55	1.18	40.1	36.0	0.98
60	1.16	39.8	37.5	0.98

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	4.6	32.7	117	59.5	07	08	07
10	4.7	33.1	122	61.9	07	09	07
15	4.6	32.7	103	52.3	08	09	08
20	5.8	41.2	118	59.9	08	09	08
25	5.7	40.1	118	59.9	09	10	09
30	5.8	40.5	113	57.4	09	10	09
35	4.6	32.7	114	57.9	11	11	10
40	4.8	34.2	123	62.4	11	12	11
45	4.6	32.7	111	56.3	11	12	11
50	5.6	39.8	113	57.4	12	13	12
55	5.7	40.1	110	55.8	12	13	12
60	5.6	39.8	112	56.9	13	13	12

Subject # 7
External Frame
Pack Weight: 43.50 lb
% Lean Body Weight: 43.1

Age: 21
Height: 162.2 cm
Weight: 59.8 kg
% Body Fat: 20.7

min	VO_2 l/min	%VO_2 max	V_E l/min	R
05	0.90	30.3	29.0	1.00
10	0.94	31.7	30.0	0.96
15	0.88	29.9	27.5	0.96
20	1.17	39.4	34.0	0.98
25	1.14	38.4	34.5	0.98
30	1.17	39.4	36.0	0.97
35	0.94	31.7	30.5	0.98
40	0.91	30.6	30.0	0.96
45	0.94	31.5	31.0	0.96
50	1.13	38.0	34.5	0.94
55	1.14	38.3	35.5	0.96
60	1.15	38.7	36.0	0.95

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	4.3	30.3	115	58.4	09	12	09
10	4.6	32.0	118	59.9	11	14	12
15	4.2	29.9	104	52.8	11	14	13
20	5.6	39.4	119	60.4	11	14	12
25	5.4	38.4	120	60.9	12	15	12
30	5.6	39.4	115	58.4	12	16	12
35	4.5	31.7	106	53.8	12	16	12
40	4.4	31.6	109	55.3	12	16	12
45	4.4	31.3	104	52.8	13	16	12
50	5.4	38.0	117	59.4	13	16	13
55	5.4	38.4	114	57.9	13	17	14
60	5.5	38.7	113	57.4	13	17	14

Subject # 8
Internal Frame
Pack Weight: 55.60 lb
% Lean Body Weight: 50.3

Age: 21
Height: 168.1 cm
Weight: 76.4 kg
% Body Fat: 35.3

min	VO_2 l/min	$\%VO_2$ max	V_E l/min	R
05	1.38	49.5	36.0	0.98
10	1.40	50.1	39.0	1.00
15	1.40	50.1	38.0	0.96
20	1.68	60.3	43.5	1.00
25	1.58	56.7	45.0	1.00
30	1.74	62.5	44.0	0.96
35	1.40	50.1	38.0	0.95
40	1.33	47.9	38.0	0.95
45	1.41	50.7	38.5	0.94
50	1.70	61.1	42.5	0.96
55	1.72	61.9	45.0	0.96
60	1.61	58.1	47.5	1.01

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.2	50.0	129	67.9	09	09	11
10	5.2	50.5	136	71.6	11	11	11
15	5.2	50.5	135	71.1	11	13	13
20	6.2	60.1	153	80.5	13	14	14
25	5.9	56.7	146	76.8	13	13	14
30	6.5	62.5	157	82.6	13	14	14
35	5.2	50.0	144	75.8	13	15	14
40	5.0	47.6	149	78.4	13	14	14
45	5.3	51.0	151	78.9	13	14	14
50	6.4	61.1	163	85.8	14	15	14
55	6.4	62.0	167	87.9	14	15	14
60	6.0	58.2	169	88.7	14	14	14

Subject # 8
External Frame
Pack Weight: 55.00 lb
% Lean Body Weight: 49.7

Age: 21
Height: 168.1 cm
Weight: 75.6 kg
% Body Fat: 35.3

min	VO_2 min	$\%VO_2$ max	V_E min	R
05	1.50	54.2	38.5	0.90
10	1.47	53.0	38.0	0.90
15	1.42	51.5	38.0	0.90
20	1.72	62.3	43.5	0.92
25	1.78	64.4	45.5	0.90
30	1.78	64.4	46.5	0.91
35	1.43	51.9	39.0	0.86
40	1.51	54.8	39.0	0.85
45	1.48	53.8	38.5	0.85
50	1.77	64.2	45.5	0.88
55	1.82	65.8	46.0	0.89
60	1.77	64.2	46.5	0.88

min	MET	%MET max	HR beats min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.6	54.3	133	70.0	08	08	08
10	5.6	53.4	128	67.4	08	08	08
15	5.4	51.9	129	67.9	09	09	09
20	6.5	62.5	140	73.8	11	11	11
25	6.7	64.4	147	77.4	12	13	13
30	6.7	64.4	150	79.0	13	13	13
35	5.4	51.9	140	73.7	13	13	13
40	5.8	55.3	138	72.6	13	13	13
45	5.6	53.8	138	72.6	13	14	13
50	6.7	64.4	147	77.4	13	15	13
55	6.9	66.3	149	78.4	13	15	15
60	6.7	64.4	150	78.9	13	15	15

Subject # 9
Internal Frame
Pack Weight: 44.50 lb
% Lean Body Weight: 43.8

Age: 19
Height: 164.5 cm
Weight: 61.1 kg
% Body Fat: 26.3

min	VO_2 l/min	%VO_2 max	V_E l/min	R
05	1.06	45.5	29.5	0.87
10	0.94	40.3	29.5	0.90
15	0.97	41.6	30.5	0.90
20	1.17	50.0	29.0	0.90
25	1.17	50.1	35.0	0.90
30	1.25	53.5	36.5	0.89
35	1.00	42.9	31.5	0.88
40	1.09	46.7	29.5	0.86
45	1.08	46.3	30.0	0.84
50	1.30	55.5	35.5	0.85
55	1.31	56.3	37.0	0.88
60	1.31	56.1	37.5	0.88

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.0	45.6	148	74.0	08	08	09
10	4.4	40.3	146	73.0	07	09	09
15	4.5	41.7	146	73.0	09	11	11
20	5.5	50.1	152	76.0	11	13	13
25	5.5	50.2	158	79.0	11	13	13
30	5.8	53.6	163	81.5	12	13	13
35	4.7	43.0	149	74.5	11	13	13
40	5.1	46.9	153	76.5	12	14	13
45	5.1	46.4	138	69.0	13	15	14
50	6.0	55.5	153	76.5	13	15	13
55	6.1	56.4	155	77.5	13	16	14
60	6.1	52.2	158	79.0	13	17	15

Subject # 9
External Frame
Pack Weight: 45.00 lb
% Lean Body Weight: 44.2

Age: 19
Height: 164.5 cm
Weight: 61.9 kg
% Body Fat: 26.3

min	VO_2 l/min	%VO_2 max	V_E l/min	R
05	1.21	51.2	37.5	0.95
10	1.18	50.0	36.5	0.94
15	1.20	50.7	36.5	0.96
20	1.45	61.4	44.5	0.97
25	1.42	60.2	44.0	0.96
30	1.44	61.4	43.5	0.96
35	1.16	49.2	38.0	0.93
40	1.16	49.2	37.0	0.92
45	1.18	50.1	37.5	0.92
50	1.39	59.0	42.5	0.91
55	1.40	59.3	44.5	0.93
60	1.40	59.7	44.4	0.92

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.6	51.4	156	78.0	09	13	13
10	5.4	50.0	152	76.0	13	15	14
15	5.5	50.9	152	76.0	13	13	13
20	6.7	61.5	166	83.0	13	15	14
25	6.5	60.1	163	81.5	13	15	15
30	6.7	61.5	152	76.0	14	15	14
35	5.4	49.5	152	76.0	13	16	17
40	5.4	49.5	156	78.0	14	17	16
45	5.5	50.5	153	76.5	14	17	16
50	6.4	59.2	163	81.5	14	19	17
55	6.5	59.6	161	80.5	14	19	17
60	6.5	59.6	161	80.5	15	19	17

Subject # 10
Internal Frame
Pack Weight: 42.75 lb
% Lean Body Weight: 42.1

Age: 33
Height: 162.2 cm
Weight: 58.7 kg
% Body Fat: 21.5

min	VO_2 l/min	% VO_2 max	V_E l/min	R
05	1.13	43.9	29.5	0.95
10	1.01	39.5	26.5	0.93
15	1.09	42.3	28.0	0.92
20	1.23	47.9	32.0	0.92
25	1.25	48.7	32.5	0.92
30	1.27	49.4	32.0	0.93
35	1.03	40.0	28.0	0.90
40	0.96	37.3	27.0	0.88
45	1.00	39.2	30.0	0.86
50	1.26	48.9	34.0	0.88
55	1.28	49.7	33.0	0.88
60	1.32	51.4	34.0	0.88

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.5	44.0	114	62.6	08	09	09
10	4.9	39.2	109	59.9	09	11	09
15	5.3	42.4	113	62.1	09	12	09
20	6.0	48.0	121	66.5	09	13	09
25	6.0	48.4	117	64.3	11	13	10
30	6.2	49.6	115	63.2	09	13	09
35	5.0	40.0	107	58.8	09	14	09
40	4.7	37.6	107	58.8	09	13	09
45	4.9	39.2	107	58.8	09	11	09
50	6.2	49.2	118	64.8	09	10	10
55	6.2	49.6	120	66.0	09	11	09
60	6.4	51.2	123	67.6	10	12	11

Subject # 10
External Frame
Pack Weight: 42.50 lb
% Lean Body Weight: 41.9

Age: 33
Height: 162.2 cm
Weight: 58.4 kg
% Body Fat: 21.5

min	VO_2 l/min	%VO_2 max	V_E l/min	R
05	1.04	40.9	33.0	0.99
10	0.99	38.7	29.5	0.96
15	0.97	38.1	29.5	0.95
20	1.29	50.4	37.5	0.96
25	1.33	52.2	40.5	0.96
30	1.29	50.7	39.0	0.95
35	1.10	43.1	35.0	0.98
40	1.02	40.0	30.5	0.92
45	1.04	40.7	34.5	0.92
50	1.23	48.2	34.5	0.92
55	1.30	50.8	37.5	0.91
60	1.26	49.5	37.0	0.93

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	5.1	40.9	106	58.2	09	11	12
10	4.8	38.6	102	56.0	10	11	13
15	4.8	38.1	99	54.4	10	12	13
20	6.3	50.3	113	62.1	13	13	16
25	6.5	52.2	117	64.3	13	13	16
30	6.3	50.6	116	63.7	11	13	16
35	5.4	43.1	112	61.5	13	14	17
40	5.0	40.0	99	54.4	13	13	17
45	5.1	40.7	108	59.3	13	15	17
50	6.0	48.1	114	62.6	13	15	17
55	6.3	50.7	114	62.6	13	14	17
60	6.2	49.5	113	62.1	13	14	17

Subject # 11
Internal Frame
Pack Weight: 41.25 lb
% Lean Body Weight: 40.5

Age: 26
Height: 168.7 cm
Weight: 56.7 kg
% Body Fat: 18.3

min	VO_2 l/min	%VO_2 max	V_E l/min	R
05	0.70	25.7	22.5	0.98
10	0.64	23.6	23.0	0.98
15	0.79	29.2	25.5	0.97
20	0.91	33.7	29.5	0.98
25	0.97	35.8	29.0	0.98
30	0.94	35.0	30.0	1.00
35	0.69	25.5	26.5	0.98
40	0.71	26.3	25.0	0.97
45	0.75	27.8	25.5	0.98
50	0.94	34.9	31.5	0.98
55	0.88	32.5	28.5	0.98
60	0.93	34.3	29.5	0.96

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	3.5	25.7	73	38.7	07	09	09
10	3.2	23.5	82	43.8	09	10	10
15	4.0	29.4	82	43.8	10	10	11
20	4.6	33.8	92	48.9	11	12	12
25	4.9	36.0	92	48.9	12	13	13
30	4.8	34.9	97	51.6	13	15	13
35	3.5	25.7	88	46.8	13	15	13
40	3.6	26.1	89	47.3	13	15	13
45	3.8	27.9	88	46.8	13	15	13
50	4.8	34.9	97	51.6	13	15	14
55	4.4	32.4	97	51.6	13	15	13
60	4.6	34.2	96	51.1	13	15	13

Subject # 11
External Frame
Pack Weight: 41.00 lb
% Lean Body Weight: 40.2

Age: 26
Height: 168.7 cm
Weight: 56.5 kg
% Body Fat: 18.3

min	VO_2 l/min	$\%VO_2$ max	V_E l/min	R
05	0.72	27.0	24.0	0.99
10	0.69	25.7	22.0	1.00
15	0.68	25.3	23.0	0.99
20	0.94	35.0	28.5	1.01
25	0.90	33.4	30.5	1.00
30	0.96	35.6	29.5	1.00
35	0.69	25.7	26.5	1.02
40	0.69	25.6	25.0	0.98
45	0.69	25.7	25.0	0.95
50	0.90	33.6	30.5	0.94
55	0.91	33.9	30.5	0.94
60	0.92	34.1	30.5	0.94

min	MET	%MET max	HR beats/min	%HR max	RPE chest	RPE shoulders	RPE legs
05	3.6	26.8	85	45.2	07	06	09
10	3.5	25.7	79	42.0	07	08	09
15	3.4	25.4	71	37.8	09	09	09
20	4.8	35.3	96	51.1	09	10	10
25	4.6	33.5	91	48.4	10	11	11
30	4.8	35.7	89	47.3	11	12	12
35	3.5	25.7	82	43.6	11	12	13
40	3.5	25.7	77	41.0	11	12	13
45	3.5	25.7	76	40.4	11	12	13
50	4.6	33.5	90	47.9	12	12	12
55	4.6	33.9	99	52.7	12	13	12
60	4.6	34.2	90	47.9	12	12	12

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