COMPARISON OF PHYSIOLOGICAL AND BIOMECHANICAL VARIABLES OF THE AIRBORNE SHUFFLE COMPARED TO STANDARD WALKING

by

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ABSTRACT

The purpose of this study was to examine the effect of the airborne shuffle on oxygen cost, HR, RER, and stride length compared to standard walking at 3 speeds (2.5 mph, 3.0 mph, and 3.5 mph) while loaded with the standard combat load. United States Army Reserve Officer Training Course cadets (N = 20; mean age = 22 years) participated in the study. The laboratory tests examined oxygen cost, heart rate, respiratory exchange ratio, and stride length. There was a statistically significant increase in oxygen cost ($p < .001$), heart rate ($p < .001$), respiratory exchange ratio ($p < .001$), and stride length ($p < .001$) across all speeds. Overall, data examination reveals that the use of the airborne shuffle is not a more economical modality while carrying a combat load, when compared to standard walking.

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CHAPTER I

INTRODUCTION

In general, load carriage is considered a strenuous muscular task and any energy saving attributed to improved economy could contribute to improved performance of tactical skills and reduced fatigue (Datta & Ramanathan, 1971). The minimum load carried in the United States Army is the combat load consisting of mission-essential equipment needed for survival on the battlefield. The combat load includes three categories, the fighting load, the approach march load, and the emergency approach march load (“Foot marches,” 1990). The mass of load carriage is determined by the soldier’s individual body mass, duty position, and mission needs (Knapik, Reynolds, & Harman, 2004). During the 2003 operations in Afghanistan, duty positions were evaluated revealing the average mass of a fighting load was 29 kg, an approach march load was 46 kg, and an emergency approach march load was 60 kg (Dean, 2004). Historically, there are several methods of load carriage including head, rucksack, double pack, rice bag, sherpa, yoke, and hands (Datta & Ramanathan, 1971). Soldiers most commonly use the rucksack method and are encouraged to carry loads with the weight high on the back, distributed between the shoulders and hips. However, while on uneven terrain, it is suggested that loads are better carried on the low or mid-back (Knapik et al., 2004). Air space should be maintained between the pack and the body using packboards to keep the back dry ("Foot marches," 1958). The most energy efficient method of load carriage for military personnel is carrying the center of mass of the load as close as possible to the center of mass of the body (Knapik et al., 2004).

The military's specific needs for load carriage have prompted the evolution of the rucksack. In 2001, the United States Army began using the Modular Lightweight Load-Carrying Equipment (MOLLE) pack (Knapik et al., 2004). The packing method used for the MOLLE pack is dependent on the needs of the mission. In general, heavier items are packed toward the top of the pack, with the most superficial items being items that the soldier needs to access quickly, such as seasonal items including Gortex rain gear. The outer pockets of the MOLLE pack are typically used for Meals Ready to Eat (MRE's) and a clean set of Army Combat Uniforms (ACU's). The typical packing list required for training road marches is 35-40 lbs ("Enlisted green platoon," 2009; "Basic standards of the airborne," 2011; "Foot marches," 1990).

During training and combat situations, the soldier is discouraged from running while carrying a combat load due to the increased likelihood of injury. In emergency situations or during time-dependent missions it is acceptable to "trot" ("How to succeed," n.d.). In the US Army, this observed trot is typically referred to as the airborne shuffle. There is no documented definition or biomechanical analysis of what constitutes an airborne shuffle. Airborne shuffle is a term used in US Army jargon to describe a slow jog while carrying a combat load. The airborne shuffle is typically used when carrying a rucksack to avoid common injuries associated with load bearing marches such as fractures, blisters, and knee injuries (Knapik et al., 2004). During marches, overstriding while torso loaded is discouraged because "continuous overstriding, or too long a pace, can result in needless injury, particularly to the leg muscles and the tendon sheaths"

("Foot marches," 1958, p. 17). The airborne shuffle has been described by US Army personnel as a default movement the body makes when a person tries to run or jog while torso loaded with a rucksack (LTC J. Miller, personal communication, October 19, 2012). From the 101st Airborne Division (2011), air assault candidates must maintain a minimum pace of 3.0 mph to complete the required 12 mile tactical ruck march in 4 hours as part of the physical requirements for graduation. Therefore, it can be deduced that the speed at which the airborne shuffle occurs is approximately 3.0 mph.

The physiological response of oxygen consumption while carrying a rucksack and performing the airborne shuffle is a topic about which little is known. The economy of different methods of load carriage and the physiological response of the body to load carriage have been studied (Datta & Ramanathan, 1971; Legg, 1985), but economy research specifically on the airborne shuffle is lacking.

Purpose Statement

The purpose of this study was to compare the oxygen cost, heart rate (HR), respiratory exchange ratio (RER), and stride length of the airborne shuffle to walking with a torso load at multiple speeds. The dependent variables in the study were net oxygen consumption, HR, and RER. The independent variables were mode (walking or airborne shuffle) and speed (2.5, 3.0, and 3.5 mph).

Hypotheses

1. It was hypothesized that the airborne shuffle would have a higher oxygen consumption walking at all speeds (2.5, 3.0, and 3.5 mph).
2. It was hypothesized that the airborne shuffle would cause higher HRs than walking at all speeds (2.5, 3.0, and 3.5 mph).

3. It was hypothesized that the RER would be higher while using the airborne shuffle as compared to walking at all speed (2.5, 3.0, and 3.5 mph).
4. It was hypothesized that shorter stride lengths would be used during the airborne shuffle as compared to walking at all speeds (2.5, 3.0, 3.5 mph).

Definition of Terms

1. Airborne shuffle: A term used in the US Army to describe the slow jog influenced by carrying a combat load (LTC J. Miller, personal communication, October 19, 2012), characterized by rapid lower leg movement accompanied by minimal stride length (Sgt. C. Clark, personal communication, March 4, 2013).
2. Average stride length: The distance between steps calculated by counting the numbers of left leg strides divided by the total distance covered during the 4^{th} and 5^{th} minutes.
3. Economy: The steady-state aerobic demand for a given sub-maximal speed of walking or running (Martin, Heise, & Morgan, 1993).
4. Net oxygen consumption: The difference between the average oxygen cost of the 4^{th} and 5^{th} minute and standing resting oxygen consumption [(4^{th} minute oxygen consumption + 5^{th} minute oxygen consumption/2) – (resting oxygen consumption) = net oxygen consumption].
5. Rucksack: A large bag, usually having two straps and a supporting frame, carried on the back and often used by climbers and campers.
6. Torso-borne load/Torso loaded: Load placed on the torso of the body in addition to the uniform, helmet, and boots of an individual, typically in reference to

military personnel (Frykman, Merullo, Banderet, Gregorczyk, & Hasselquist, 2012).

7. Walking: A movement consisting of two distinct phases (swing phase and support phase); progressive alternation of leading legs and continuous contact with the supporting surface (Payne & Isaacs, 2008).

Basic Assumptions

The researcher assumed that all the participants followed pre-testing instructions including: (a) no alcohol consumption 24 hours prior to testing, (b) no caffeine or nicotine consumption 2 hours prior to testing, (c) maintenance of proper hydration a minimum of 48 hours prior to testing, and (d) obtaining a minimum of 7 hours of sleep the night before testing.

Delimitations

1. The rucksack that was used for torso loading was pre-packed to ensure consistency in weight and weight distribution across participants.
2. All participants wore the same type of clothing and footwear, consisting of US Army approved Army Combat Uniform (ACU's) and boots.
3. Participants were required to complete all testing sessions to be included in the data set.

Limitations

1. It was a challenge to ensure the fidelity of the airborne shuffle movement pattern as there is no documented description of the airborne shuffle.

Significance of the Study

Results from this study will enable a better understanding of the most economical means of locomotion for individuals carrying a 35 lb rucksack, the weight of the standard US Army combat load. Determining the most economical mode at which a standard combat load can be carried translates into increased physical longevity on the battlefield. According to Daniels (2005, p. 25), it is desirable to increase economy, because it allows the individual to perform at a faster pace without increasing energy cost. Load carriage is considered a strenuous muscular task; thus increasing economy and energy conservation of load carriage would contribute to improved performance of the task and decreased fatigue (Datta & Ramanathan, 1971).

CHAPTER II

LITERATURE REVIEW

Military personnel are expected to carry heavy loads while completing tactical skills. This movement of troops and equipment, mainly by foot, with limited vehicle support, is referred to as a foot march (Dijk, 2007). In the US Army, a successful foot march is “when troops arrive at their destination at the prescribed time and they are physically able to execute their tactical mission. They are also able to execute their tactical mission” ("Foot marches," 1990, pp. 1-3). In the US Army, the mass of the load carried can vary depending on the soldier’s duty position and the mission. Additionally, soldiers must prepare for a variety of threats in complicated operational environments ("Army physical readiness," 2010). Operational environments and training often include the use of loaded rucksacks with mission essential equipment (Dijik, 2007; "Foot marches," 1990). United States Army specialty schools have standards for completing tactical marches within specific time constraints, while carrying a loaded rucksack ("Basic standards of the airborne," 2011; “Enlisted green platoon," 2009). The method of torso load used in today’s US Army, while on foot, has been impacted by the needs of the military, the history of military load carriage, injuries associated with load carriage, and the metabolic costs of moving a load. In the US Army, the airborne shuffle is often used to move quickly on foot while carrying a combat load.

Torso Loading Methods

There are a number of methods used for load carriage worldwide. Factors that influence which method of load carriage is used include culture, load weight, load size, load shape, terrain, climate, clothing, duration and distance of load carriage, and the individual's physical fitness level (Legg, 1985). These factors could prove to be particularly important in specific populations such as military personnel in combat situations.

As load carriage on foot is an important aspect of military movement, it is important to identify the most economical means of load carriage and the most reasonable scenario in which that method of load carriage may be most useful. In 1971, Datta and Ramanathan completed a comparative study of oxygen cost while moving at a speed of 5 kph with a 30 kg load using the seven most common modes of load carriage including head, rucksack, double pack, rice bag, sherpa, yoke, and hands. When oxygen consumption, minute ventilation, pulse rate during steady state exercise, and 5 minute post-exercise recovery were measured. Post-hoc measures indicated a significant difference in HR, with the HR being higher with the hands method as compared to all other methods. Minute ventilation was significantly higher in the double pack method when compared to the rucksack method. The superior economy of the double pack method was attributed to the closeness of the load to the body and the equal distribution of weight among the two packs (Datta & Ramanathan, 1971). Energy expenditure, HR, and pulmonary ventilation were all affected by the method of load carriage used, while individual differences in the test participants affected only the cardio-pulmonary parameters. This lack of significant difference indicates that the difference in values is a consequence of carriage method used (Datta & Ramanathan, 1971).

In the head mode, the load was carried in a basket and placed on top of the head. The rucksack method, most commonly used by armed forces and small children, consisted of a loaded rucksack strapped across the shoulders with the load positioned high on the back. The double pack method was characterized by two packs equally dividing the load through straps across the front and back of the shoulders with the bottoms of the packs loosely tied together. During the rice bag mode, the load was placed in a gunny sack and the load was supported on the back with the two corners of the gunny sack held by either hooks or the hands. The sherpa method, a method still used by sub-Himalayan residents and tea pickers, loaded the body through a sack, the sack strapped around the forehead, allowing the hands to remain free. The yoke method divided the load equally between two ends of bamboo with the load attached to the bamboo by three ropes to suspend the load and prevent dragging on the ground. The bamboo was balanced across a single side of the body on the shoulder while carried. The hands method is typically used when transporting liquids and consists of two canvas bags with the load divided equally between the two bags (Datta & Ramanathan, 1971).

In a non-specific population, the double pack method was found to be the most ergonomic and energy efficient method of load carriage with the head mode being the second best choice, and the rucksack method being the third best selection for load carriage. The least energy efficient mode of carriage was the hands method, with the rice bag, and sherpa methods being economically intermediate (Datta & Ramanathan, 1971). The authors concluded that the double pack method is the most efficient because the HR and energy cost were the least. They went further to indicate that the head method was the least desirable in terms of efficiency.

Therefore, the most energy efficient means of load carriage is keeping the loads center of mass as close as possible to the body's center of mass (Datta & Ramanathan, 1971; Knapik, 1989; Knapik et al., 2004). According to Legg's study (1985) which compared 6 different load carrying techniques "a combined front and backpack (double pack method), or carriage of loads around the waist, tend to incur the lowest energy cost for a given load, as lateral and anteroposterior stability is optimized," (p. 197). The results of Datta and Ramanathan (1971) as well as Legg (1985) become pertinent when considering the needs of military personnel because it is important to understand the most economical means of load carriage while on foot.

Rationale for the Military's Use of the Rucksack for Load Carriage

In combat settings, the way a load is carried and packed can contribute to the success of a mission and the likelihood of survival of the soldier. Although research indicates that the most ergonomically and economically effective method of load carriage is the double pack method and head method (Datta & Ramanathan, 1971), the rucksack method remains the mode used in military environments (Datta & Ramanathan, 1971; "Foot marches," 1990).

The method of load carriage used by a soldier is influenced by a soldier's ability to move while carrying the load. While loaded with equipment, a soldier must maintain the ability to tactically function, complete mission essential tasks, and survive ("Foot marches," 1990). Load carriage methods such as the head, double pack, rice bag, sherpa, yoke, and hands methods do not allow for the completion of tactical skills while carrying a load. The double pack method requires the load be equally divided into separate packs. Consequences of dividing the load are that the packs cannot be fitted or removed easily which makes the double pack method difficult to use in situations where it is necessary to load and/or unload quickly (Datta & Ramanathan, 1971). The head method is effective, but not suitable for military environments due to the restriction of one arm, limited body movement as a whole, and instability on uneven terrain. The rice bag method also restricts the use of the upper extremities and is the most high risk method of load carriage in terms of injury, as the body is stooped forward with the spinal column bearing the burden of the load. Although the sherpa method does allow for hands free movement, it requires great practice and does not offer any special advantage over the rucksack method, especial in military populations. The yoke method is not functional for military environments as it requires balancing a bamboo stick and causes the load to be carried away from the body's core.

An advantage of using the rucksack method is that the arms and hands are free for tactical skills and carrying a weapon. In the rucksack method, there is less restriction of the body and less surface area covered so thermoregulation is not hampered (Datta & Ramanathan, 1971). This advantage, combined with high efficiency when compared with other methods, make the rucksack an attractive method of load carriage in combat situations.

Despite the advantages to using the rucksack method of load carriage, there are disadvantages to this method. The rucksack method causes a forward tilt of the trunk and head which may increase as the load becomes greater (Harman, Ki, Frykman, & Pandorf, 2000), burdening the structures of the spinal column (Datta & Ramanathan, 1971). The body assumes a “stooped” position because the shoulders are constantly pulled back, retracting the shoulder girdle, and allowing the straps of the rucksack to cut into the trapezius muscles (Datta & Ramanathan, 1971; Legg, 1985). The retraction of the shoulder girdle could lead to chest restrictions which may impede combat function (Legg, 1985). In spite of the disadvantages, the rucksack method is the most functional form of load carriage for military populations. While studies (Datta & Ramanathan, 1971; Legg, 1985) have shown the rucksack method to be most economical and functional in military environments, the pack itself has been adapted with features that are particularly useful in many combat environments.

Military Adaptations to the Rucksack

The two methods of rucksack load carriage available for soldiers are the All-Purpose Lightweight Individual-Carrying Equipment (ALICE) pack and the Modular Lightweight Load-Carrying Equipment (MOLLE) pack. The ALICE pack first appeared in 1973-1974 and has been used for more than 35 years. This pack is known for its durability and stability when transporting heavy loads. Ventilation is provided to the back by an external frame that holds the ALICE pack away from the body allowing air flow (Knapik et al., 2004). This is a particularly useful feature because without the external frame the rucksack would maintain contact with the body at all times making it more challenging to thermoregulate (Legg, 1985). Unfortunately, the ventilation feature limits the ability to adjust the pack to the individuals comfort (Knapik et al., 2004).

Consequently, the MOLLE pack was developed due to the need for a modular system with better equipment compatibility and features for fitting specialized equipment. The Marine Corps began using the MOLLE pack in 1999 and the Army in

2001 (Ling, Houston, Tasi, Chui, & Kirk, 2004). The MOLLE pack consists of a system containing a main pack with an external polymer frame with anatomical contours, butt pack, and load-bearing vest with removable pockets to allow for different size objects. A sleeping bag compartment and pouches attach to the external frame. The MOLLE pack features a patrol pack that can be detached and used separately. The shoulder straps on the pack are padded and adjustable to allow shifting and equal distribution of weight to different anatomical locations of the body. A waist belt is also used to secure the rucksack to the body and has been found to contribute to efficiency of locomotion by reducing the pressure applied to the shoulders and increasing comfort while carrying additional loads (Legg, 1985). The evolution of the rucksack has been achieved through a long history of military load carriage experience and the advancement of combat equipment used during battle.

History of Military Load Carriage

Before the 18th century, military personnel rarely carried more than 15 kg of additional weight while marching (Knapik, 1989). Warfare has advanced from using armored cavalry in the middle ages to the development of firearms during the Renaissance. The advent of firearms required additional equipment that weighed up to 23kg. Since then, the development of new weapons and equipment has increased the load mass carried by soldiers. Since the Industrial Revolution, the height and weight of the average British and American soldier have increased, allowing for heavier loads to be carried on foot. Despite the ability of soldiers to carry heavier loads, soldiers continue to struggle with the ability to carry mission essential equipment on foot without overloading the body and the ability to maintain tactical mobility while carrying that equipment (Knapik, 1989).

From 1948 to 1950, a board was created at Fort Benning, Georgia to study the individual soldier's mission within the military unit and the amount of load bearing equipment for each position. The board documented loads ranging from 25 kg for rifleman to 50 kg for soldiers carrying ammunition. The board coordinated with the Office of the Surgeon General in order to make the soldier more combat efficient by load reduction. The board decided that the energy used for marching, excluding the basal metabolic rate, should not exceed 3,680 kcal/day. The board recommended that the individual rifleman should not carry more than 18 kg in work conditions and that 25 kg was the recommended maximum mass of the march load (Bailey & McDermott, 1952). In 1964, roughly a decade later, the US Army Infantry Combat Developments Agency encouraged the weight recommendations of 18 kg or 30% of a soldier's body weight and 25 kg or 45% of body weight for the conditioned soldier. The idea of limiting the load mass based on an individual's body weight became known as "load echeloning," and defined a fighting load as the existence load which consisted of mission essential equipment ("A study to conserve," 1964).

Research conducted by Burba (1986) aided the infantry school in giving guidance on suggested load carriage weight for the soldier based on body weight. The optimal load for a soldier to carry is 30% of his or her own body weight and the maximum load carried should not exceed 45% (Burba, 1986). During 1987, the US Army Development and Employment Agency (ADEA) continued to evolve the concept of load echeloning into what the present day US Army calls the combat load. The combat load is the mission essential equipment for the individual soldier to fight and survive a combat mission ("Foot marches," 1990). In 1989, a US Army infantry cadet's recommended approach march load was not to exceed 33 kg or 45% of the individual's body weight. While the combat load for an infantry cadet should not exceed 22 kg or 30% of the soldier's body weight ("A study to reduce," 1962; "A study to conserve," 1964). According the US Army Medical Research and Development Command, loads have been reduced due to lighter equipment, load tailoring, auxiliary transport systems, and doctrinal changes. Today, the US Army combat load has three categories of load which can vary in weight depending on the purpose of the mission ("Foot marches," 1990).

Current US Army combat load. The three categories of US Army combat load include the fighting load, the approach march load, and the emergency approach march load ("Foot marches," 1990). The fighting load, also called the assault load, should not exceed 48 pounds ("Foot marches," 1990) and includes bayonet, weapon, helmet, clothes, load bearing equipment, and a limited amount of ammunition. This load is designed to facilitate stealthy missions where hand-to-hand combat is necessary, therefore, the soldier carries minimal ammunition. The fighting load is the lightest of the rucksack loads as assault troops should be burdened with the most minimal load possible (Dijk, 2007). The weight of the assault pack may exceed the recommended 48 lbs to make accommodations for machine gun ammunition, mortar rounds, antitank weapons, and radio equipment if trucks or trailers are unavailable. Loads above 48 lbs have been found to limit mobility and must be redistributed so weapons are easily accessible and the rucksack can be shed before enemy contact (Dijk, 2007; "Foot marches," 1990).

The approach march load should not exceed 72 lbs and includes basic load ammunition, clothing, weapon, load bearing equipment, a small assault pack, or a lightly loaded rucksack or poncho roll (Dijk, 2007). When preparing the packing list for the approach march load, the commander should consider the carrying capability of a soldier without degrading physical combat effectiveness or the soldier's psychological perspective ("Foot marches," 1990). The goal of the approach march load is to supply enough ammunition and equipment for fighting and survival until re-supply is possible.

In extreme circumstances or when terrain is not conducive for vehicles or air resources are unavailable, it may be necessary to send a soldier carrying an emergency approach march load into the battlefield. This soldier is typically a highly skilled, highly conditioned individual, who can carry loads of up to 54.5 kg at a pace of 20 km per day for several days. Loads of up to 68 kg are feasible, but the soldier will usually become fatigued or sometimes injured (Dijk, 2007; "Foot marches," 1990).

During the Afghanistan Operations in 2003, the load carriage mass of different duty positions were evaluated (Dean, 2004). Table 1 depicts 12 out of the 29 positions that were examined, indicating that load varied according to the soldier's duty position. The average mass of the fighting load was 29 kg, the approach march load was 46 kg, and the emergency approach march load was an average of 60 kg. According to Cathcart, Richardson, and Campbell (1923) energy cost, per unit total weight and distance, was the least when loads were equal to 40% of the soldier's body weight. A slightly lower energy cost, per unit total weight and distance, was found when men were allowed to self-pace with loads of 44-59% of their body weight (Hughes & Goldman, 1970).

Table 1

Average Mass of Load Carriage by Infantry Soldiers During Dismounted Afghanistan Operations April-May 2003

Duty position	Fighting load (kg)	Approach march load (kg)	Emergency march load
Rifleman	29	43	58
M203 grenadier	32	48	62
Automatic rifleman	36	50	64
Weapons squad leader	28	45	60
M240B assistant gunner	32	55	67
Fire support noncommissioned officer	24	41	65
Company first sergeant	29	41	57
Mortar section leader	26	50	68
60-mm mortar gunner	29	49	61
Forward observer	26	41	58
Sapper Engineer	27	43	60
Platoon Medic	25	42	54

Note: Adapted from “The Modern Warrior’s Combat Load. Dismounted Operations in Afghanistan, April-May 2003,” by C. E. Dean, 2004, Ft Leavenworth, KS: Army Center of Lessons Learned.

US Army Standards for Torso Loaded Marches

At a minimum, soldiers are expected to be physically conditioned to carry their individual combat load, as determined by the commander ("Foot marches," 1990). The "Enlisted green platoon information packet (2009)," specifically states “soldiers must be able to move quickly, carry a load (rucksack) of equipment, and be physically able to perform their mission after extended marching” (2009, p. 10). The required packing list varies depending on the season, with the winter load being heavier than the summer load due to carrying an extra dry uniform ("Foot marches," 1990). The US Army defines the winter season as October 15th through April 14th and the summer season as April 15th through October 14th ("Warrior leader course," 2012).

Graduation for job specific schools in the US Army is partially contingent on the cadet’s ability to pass various physical requirements, some of which include tactical marches with a loaded rucksack. For example, a US Army Ranger cadet must march at a rate no slower than a 15-minute per mile pace to complete a 12 mile foot march, while carrying a 35 lb rucksack ("Basic standards of the airborne," 2011). Candidates of the 101st Airborne Division (Air Assault) at Fort Campbell must move at a minimum speed of 3.0 mph in order to complete the expected 12 mile tactical foot march in 4 hours while loaded with a MOLLE pack (assault pack) and their weapon in the ready position ("Basic standards of the airborne," 2011). According to the 160th Special Operations Aviation Regiment, the standard rucksack should weigh 35-40 lbs for all road marches ("Enlisted green platoon," 2009). While loaded with a rucksack in various training and combat conditions, it is important for the soldier to be instructed on the most effective means of movement for energy conservation and mission success.

Tactical foot march technique. In an Alpha Company Pre-Ranger Success Packet (n.d.), “Proper Ruck March Techniques” are described as keeping the body weight directly over the feet with the sole of the shoe placed flat on the ground. This is accomplished by taking small steps at a steady pace. Leg muscles should be allowed to rest, by locking the knees on every step, especially when going uphill. When descending hills, it is suggested to keep the back straight and the knees bent to help absorb the shock of each step, while digging the heels into each step.

To prepare for rucksack marches, it is advised to practice walking as fast as possible while wearing a loaded rucksack. According to the Alpha Company, a soldier should not run while wearing a rucksack. If needed, a “trot” may be used, but is not advised as trotting may cause injury ("How to succeed," n.d.). A good rucksack pace is described as a “continuous movement for four miles, followed by a 10 minute break, every hour” ("How to succeed," n.d., p. 7), with varying intervals of speeds and rest dependent on the individuals physical conditioning status ("How to succeed,” n.d.). According to US Army personnel, when a soldier needs to run or “trot,” the body is only able to produce a slow jog due to the additional weight of the rucksack, despite efforts to run (LTC J. Miller, personal communication, October 19, 2012). This slow jog while loaded with a rucksack is commonly referred to as the “airborne shuffle” amongst US Army personnel (SFC F. Greenwell, personal communication, Oct. 19, 2012).

US Army Airborne Shuffle History

Documented information pertaining to the airborne shuffle is lacking, therefore personal communications with US Army personnel were used in an attempt to identify a definition and biomechanical description of the airborne shuffle. The term airborne shuffle originated during World War II, from the airborne unit. As paratroopers prepared to deploy from the aircraft they would shuffle to the door, in place of a normal walking gait, to avoid getting tangled in equipment. The term airborne shuffle is used today to describe the slow jogging movement a soldier makes while wearing a rucksack as it mimics the same movement pattern made by the airborne unit just prior to deploying from the aircraft. United States Army personnel report the airborne shuffle is used not by personal choice, but by default as the body naturally produces the movement when a soldier tries to jog or run with a loaded rucksack (LTC J. Miller, personal communication, October 19, 2012).

Consistently, the airborne shuffle has been described by US Army personal communications as an extremely slow jog while carrying a rucksack, characterized by short stride lengths (Sgt. C. Clark, personal communication, January 28, 2013). Controversy of using the airborne shuffle amongst US Army personnel resides in the subjective reports of soldiers that state the shuffle exhausts them. Some US Army personnel state that the movement of the airborne shuffle is such an awkward pace and movement that it causes fatigue and extreme burning in the calf muscles for a majority of a march.

Rationale for the airborne shuffle gait pattern. According to Army personnel, the airborne shuffle is first introduced during boot camp and has several functions within the US Army. The pace of the airborne shuffle can be calculated to be approximately 3.0 mph ("Basic standards of the airborne," 2011) and is often used as the pace for group physical training (PT) in order to slow the group as a whole to prevent slower cadets from being left behind on runs. The goal of group PT is not only to condition soldiers to carry a combat load, while conserving enough energy to perform tactical skills, but also to advocate unit cohesion. The pace of the airborne shuffle is slow enough that it may be used during formation runs as it is difficult to maintain a fast pace with large numbers of soldiers. Furthermore, the airborne shuffle may be used to meet mission time constraints from unforeseen complications from weather or terrain variances forcing the soldier to slow the average march pace. In order to make up for the lost time, the soldier may have to double-time the pace. While the soldier tries to jog or run the soldier is unable to due to additional weight from the rucksack and combat equipment; therefore, the airborne shuffle is used.

According to personal communications, the primary purpose of using the airborne shuffle is to negate injury to the knees and other joints during occupational tasks and jogging while loaded with equipment. The airborne shuffle is not a full jog or run, thus it is thought to generate fewer traumas to the body. As explained by Sgt. C. Clark (personal communication, March 4, 2013) when carrying a rucksack, running is avoided due to the potential harm to the knees and other joints from the weight of the load. Using the airborne shuffle instead of a run places minimal impact on the joints as compared to a run (Sgt. C. Clark, personal communication, March 4, 2013). Furthermore, it has been indicated by Alpha Company ("How to succeed," n.d.) that a soldier should not run while wearing a rucksack, but should "trot" if needing to avoid causing injury. According to Houglum (2005), stress can be reduced to the body by shortening the stride length during walking and running as smaller strides reduce the motion and force applied to the tendons, muscles, and ligaments. As the airborne shuffle can be categorized by the short stride lengths used, the rational of injury prevention may be a plausible rationale.

Injuries Associated with Torso Loading

Alpha Company indicates that while loaded with a rucksack, trotting (airborne shuffle) should be utilized in place of a run, and only as needed, to avoid injury. Long distance load carriage can increase injuries such as foot blisters, metatarsalgia, stress fractures, knee pain, back strains, and rucksack palsy (Knapik et al., 2004). The most common injury associated with foot marches is the foot blister (Knapik, Reynolds, Duplantis, & Jones, 1995). Incidences of the foot blister are increased as mileage or intensity of the foot march increase (Knapik et al., 1995). Metatarsalgia is nondescript pain that often results from constant overloading of the transverse ligaments of the foot and is thought to develop primarily from walking with heavy loads (Magee, 2008). In military populations, metatarsalgia is typically associated with foot strain consequent of quick change in intensity of weight bearing activity (Knapik et al., 1995). Metatarsal fractures, referred to as “march fractures,” are greatly attributed to overloading of bones during activities such as road marches (Knapik et al., 1995) and are most common after substantial increases in training mileage, training intensity, surface change, or shoe type (Anderson, Parr, & Hall, 2009). Common knee pain injures such as patellofemoral pain syndrome (PFPS), patellar tendonitis, bursitis, and ligament compromise are associated with large increases in road march mileage and/or intensity, hill climbing, and lack of proper terrain acclimatization (Knapik et al., 1995).

Furthermore, in military populations, load is suspected to impact the frequency of low back injury because heavier loads can cause trunk angle changes leading to cyclic stress amongst back muscles, ligaments, spinal discs, vertebral bodies, and nerve roots (Knapik et al., 2004). This additional stress to the back and shoulders mostly comes from wearing a rucksack alone as opposed to wearing a rucksack with a frame and a hip belt (Bessen, Belcher, & Franklin, 1987), and can lead to rucksack palsy (Knapik, 1989). Poor weight distribution, heavy loads, and long load carriage distance contribute largely to the developing signs and symptoms of rucksack palsy. Incidences of rucksack palsy can be reduced by using a backpack frame and hip belt (Bessen et al., 1987; Knapik, 1989), which helps to reduce pressure on the shoulders (Knapik et al., 2004).

On the battlefield and in training, US Army personnel use the airborne shuffle to decrease the chances of developing any of the aforementioned common injuries associated with tactical foot marches. Characteristics that put soldiers at a higher propensity to develop an injury include march distance, march intensity, march frequency, and load mass (Knapik et al., 2004). Although body weight, height, and aerobic fitness may not be as influential in injury development (Markela, Ramstad, Mattila, & Pihlamjamaki, 2006), it is important to consider fitness level and energy cost of the movement used for military tasks as this influences the intensity of the march.

Metabolic Costs of Locomotion

In general, every movement made by the body has a physiological cost. Military populations may need to walk, trot, or run while carrying a load, which can increase energy cost. According to Scott and Christie (2004), as walking or running speed increases, more myofibrils are recruited which increases energy demand, which is indicated by increased oxygen consumption values. Running economy may be described as the amount of oxygen needed by the body in relation to a person’s body weight and the submaximal speed being traveled (Daniels, 2005). Hayes, French, and Thomas (2011) indicated that the energy cost of steady speed running increases as fatigue increases at the end of a 90 minute run. This is relevant to military populations because most marches exceed 90 minutes ("Basic standards of the airborne," 2011). Therefore, it can be inferred that on marches lasting longer than 90 minutes, fatigue may increase energy expenditure and potentially compromise mission efficiency, regardless of additional load carriage.

Metabolic costs of "abnormal" gait patterns. According to Daniels (2005), economy can be improved by minimizing unnecessary extremity movements, and optimizing recruitment of motor units while simulating the movement desired. Therefore, a soldier using an ineffective mode of load carriage, or an abnormal gait pattern, could potentially have poor economy due to an increase in the number of motor units recruited to produce the movement. Furthermore, it has been concluded that gait manipulation results in significantly increased oxygen consumption values in trained female distance runners, implying gait manipulations can produce significant decrements in running economy (Tseh, Caputo, & Morgan, 2008). This information is valuable in terms of military populations because additional weight from a rucksack and protective equipment and/or use of the airborne shuffle are all forms of gait manipulation. Due to the findings of Tseh et al. (2008), it can be postulated that a soldier using the airborne shuffle instead of a walk would have an increased energy cost because the airborne shuffle is a manipulation of the soldiers normal walking gait pattern.

Footwear. A study conducted by Strydom, Van Graan, Morrison, Viljoen, and Heyns (1968), found that boot weight of 1.8-2.9 kg did not affect oxygen consumption while stepping at a slower rate of 12 steps/min. However, when the speed was increased to 24 steps/minute, oxygen consumption of participants wearing the lighter boots weighing 1.8 kg was significantly lower than the heavier boots weighing 2.2 kg (Strydom et al., 1968). In other words, as the speed was doubled from 12 steps/min to 24 steps/min, and as boot weight was increased, the oxygen cost of the participant's also increased. Jones, Toner, Daniels, and Knapik (1984) conducted a study where participants completed trials walking at speeds of 2.5, 3.5, and 4.5 mph and running at speeds of 5.5, 6.5, and 7.5 mph. Jones et al. found that when compared to wearing athletic shoes weighing 0.62 kg per pair, participants who wore boots weighing 1.78 kg per pair had a higher energy cost regardless of whether the participant was walking or running, except at the slowest speed of 2.5 mph. The boot weight used in Jones et al. (1984), was close to the lowest boot weight of 1.8 kg used in the Strydom et al. (1968), study.

Therefore, from Jones et al. (1984) it can be concluded that while walking at slower speeds of 2.5 mph, a soldier's economy should not be impacted by boot weight alone. Despite the fact that boot weight does not seem to impact economy at slower speeds, boot weight at speeds higher than 2.5 mph will yield a higher oxygen cost than when wearing an athletic shoe weighing 1.776 kg or less (Strydome et al., 1968). It can be concluded that boot weight of 1.8 kg or less will not affect the economy of an individual moving at 2.5 mph or less. Overall, the research (Jones et al. 1984; Strydom et al., 1968) indicates that the mass of footwear can influence oxygen cost. There is an expected increase energy expenditure of 7%-10% for each kilogram added to the foot of a soldier (Knapik & Reynolds, 2010). These findings implicate that a decrease in footwear mass could contribute to improved economy.

Economy of Torso Loading with Backpacks and Rucksacks

In terms of energy expenditure, gait manipulation as well as the effect of torso loading a soldier with a rucksack must be considered. According to Knapik (1989), factors such as march speed, load weight, and grade can increase the energy cost of movement. Energy cost stays the same over time during marches at a steady speed, with loads less than 40% of the soldier's body weight. However, energy cost increases progressively at speeds of 5 km/h (3.11 mph) or higher and with march loads heavier than 40% of a soldier's body weight. Energy cost has also been found to increase with speeds as low as 4 km/h (2.49 mph) with loads of 60% of the soldier's body weight (Knapik, 1995). The energy cost per unit weight is the same whether it is the weight of the backpack or body (Knapik, 1995). This is important because soldiers carry loaded rucksacks in conjunction with the additional mass of Kevlar protective equipment.

Speed and intensity. Load is not the only factor that needs to be considered when evaluating the economy of load carriage. Scott and Christie (2004) suggested that pace and load mass contribute equally to economy of movement in military populations. Mission assignments can be time dependent and sometimes require transportation of large loads while on foot. As one variable is manipulated, either speed or load mass, the kinematics and gait patterns of the soldier will be affected, ultimately changing the physiological effect or economy of the individual (Scott & Christie, 2004).

It is suggested that oxygen cost should not exceed 30-45% of maximal oxygen consumption so fatigue may be lessened during long periods of load carriage (Astrand & Rodahl, 1977; Myles & Saunders, 1979; Saha, Datta, Banerjee, & Narayane, 1979). During military marches, it is not uncommon for marches to exceed the recommended 30-40% of maximal oxygen uptake (VO_2max). According to Knapik (1989), during short duration marches, the intensity of the march can be increased from 30-40% of VO_2max to 60% of VO_2max. This information becomes pertinent when considering US Army personnel may have to carry rucksacks of up to 68 lbs (Dean, 2004) while moving at varying speeds and traveling over different grades of terrain.

Self-pacing has been shown to result in the lowest energy cost for Army individuals while load carrying. According to Knapik (1989), soldiers incur a lower energy cost when they self-pace as opposed to using a forced pace. During short time frames of 1-3.5 hours, soldiers have been found to self-pace at 45% of their VO_2max (Knapik, 1989) . During long periods of travel, 2-6 days, while load carrying; soldiers tend to use about 32% of their VO_2max when self-pacing (Knapik, 1989). Additional torso loads increase the body's caloric expenditure and oxygen cost. Factors such as increasing movement intensity, walking speed, grade, and the terrain can dramatically impact economy and oxygen cost (Knapik et al., 2004).

Stride length. In a study by Scott and Christie (2004), the top three most economical combinations of speed and load were identified when using a combination of 16 speeds (3.5-5.5 kmh^{-1}) and loads (20-50 kg). The study revealed that cadence and gait patterns were affected by load and march rate variations. Stride length increased as speed increased from 3.5 to 5.5 kmh^{-1}. However, it was suspected that the change in stride length could have been partially due to the decrease in load mass from the heavy condition of 50 kg down to the light condition of 20 kg. As indicated by Scott and Christie (2004), increased load tends to lead to "mincing" steps or a reduction in stride length. With loads ranging from 20-50 kg, soldiers were capable of maintaining 61-66% of predicted HR range with oxygen consumption of approximately 46% of the soldiers predicted maximum by adjusting march speed. Furthermore, Scott and Christie (2004) found that shorter soldiers had a higher oxygen cost due to a higher stride frequency as opposed to taller soldiers that had a longer stride length.

These data quantify the argument that soldiers are capable of reaching metabolic steady state by adjusting march speed to accommodate the load mass carried during the march (Scott & Christie, 2004). These data document that soldiers are capable of maintaining the overall physical demand of prolonged marching while torso loaded as long as the speed and load are adjusted for the conditions, ensuring combat effectiveness (Scott & Christie, 2004). The study conducted by Scott and Christie (2004) also substantiates the claim that work load should not exceed 30-40% of maximal oxygen consumption to avoid fatigue with load carriage (Astrand & Rodahl, 1977; Myles & Saunders, 1979).

Grade, terrain, and the free ride phenomenon. When a load is carried on the back at slower walking paces, it has been suggested that there is a *free-ride* phenomenon. According to the free-ride phenomenon, energy expenditure does not necessarily increase while walking at slower paces with a load carried on the back. According to Saibene and Minettie (2003), each person has a specific walking speed that can minimize the energy cost of walking per unit distance (C_w: ml/kg/m). This walking speed that corresponds to the minimum energy cost used per unit distance is referred to as the economical speed or the “optimal speed” (Falola, Delpech, & Brisswalter, 2000). Abe, Muraki, and Yasukouchi (2008) studied the energy cost of load carriage (15% of each participant’s body mass) on the back, at slower, level speeds (1.1 mph to 4.5 mph). When economical speed was studied in non-loaded and loaded conditions, with walking gradient (+/- 5%), it was concluded that the energy cost of walking per unit distance was significantly less only when the load was carried on the back in level walking conditions, at slower speeds (Abe et al., 2008). This research by Abe et al. (2008) suggests there is evidence of an economical speed similar to the free-ride phenomenon, but only when slower walking speeds are used with no gradient (Abe et al., 2008). This research absolves the free-ride theory from being associated with economy of soldiers under torso load. Abe et al. (2008) found that the existence of economical speed was only present during level walking conditions. In military settings, it is highly unlikely that foot marches will only be completed on level terrine. Furthermore, varying speeds are also used to accommodate the varying terrine and needs of mission time constraints.

Performance Associated with Torso Loading

The Army defines physical fitness as “the ability to function effectively in physical work, training, and other activities and still have enough energy left over to handle any emergencies which may arise” ("Enlisted green platoon," 2009, p. 10). In combat situations, load carriage and the effect it has on performance and fatigue are of particular interest to service members because of the contribution to survivability. According to Dijk (2007), the ability of the soldier to complete a road march as quickly as possible and the ability to complete essential tasks during or upon conclusion of a march are essential in the context of performance with load carriage. Functional relevance of conditioning drills relates to the ability to climb over obstacles and movements in urban buildings (Knapik et al., 2004). The load mass, load mass volume, and the distribution of the load within the pack can influence the incidences of injury as well as the performance of the individual (Knapik et al., 2004). Performance skills such as long distance runs, agility runs, ladder climbs, short sprints, and obstacle courses are degraded by approximately 1% to 3% per kilogram load (Knapik et al., 2004). This becomes increasingly important because soldiers must be able to carry heavy loads to the assigned destination and they must still have the ability to perform tactically after walking long distances with a load.

In a study conducted by Frykman et al. (2012), exhaustive whole-body exercise and torso loading caused more rapid fatigue and less overall work in individuals with additional torso load. All participants displayed degraded marksmanship accuracy, regardless of the load conditions (Frykman et al., 2012). It is thought that the lack of accuracy in marksmanship is due to the small movements of the rifle that results from fatigue of the upper body, fatigue-induced tremors, and elevated HR respiration (Knapik et al., 2004).

A study by Knapik, Johnson, Ang, Meiselman, and Bensel (1993), evaluated 12 male, Special Forces soldiers using both the ALICE pack and double pack method to evaluate the effect of pack, load, and march on a number of performance tests. A 20 km march was completed as quickly as possible while wearing packs weighing 34, 48, or 61 kg. Statistics revealed that pack type, load, and parch had no effect on grenade throw. Leg strength was not affected by pack type or load, but was decreased after marching. However, statistically, no significant interactions between leg strength and marching were found. Handgrip strength was not affected by pack type or load, but strength increases post march were significant. During an obstacle course, no differences were seen on account of pack type or load. After marching 20 km, a significant difference was found with soldiers taking longer to complete all obstacle course tasks except for the zig-zag (Knapik et al., 1993). This study leads to the conclusion that after prolonged marching, while carrying a combat load, soldiers should be proficient in tasks requiring grenade throws, lower body power, and grip strength. It should be noted that the soldiers overall tactical ability to move and complete tasks may be limited when performance is expected post marching.

Conclusion

A priority consideration for soldiers in the military is their ability to be proficient in military task performance while carrying loads of 34-61 kg for distances of 10-20 km (Knapik et al., 2004). When covering the same distance, Scott and Christie (2004) found that shorter soldiers had higher energy expenditures because they had to take more steps to go the same distance as taller soldiers. The airborne shuffle can be identified by “trotting” ("How to succeed," n.d.), mincing steps, or the use of a shorter stride length (Sgt. C. Clark, personal communication, March 4, 2013). Therefore, due to the findings of Scott and Christie, it is expected that while performing the airborne shuffle, with torso load, the oxygen cost of the soldier would increase as a shorter stride length is expected as compared to a walk or run. There is little information known about the physiological effect of the airborne shuffle as compared to walking and running while torso loaded. Having a better understanding of the effect of selected locomotion while on foot would enable military personnel to train using movement patterns that are most conducive for conserving energy and performing tactical skills.

CHAPTER III

METHODS

Participants

Male participants (*n* = 20), ranging from 18-33 years of age, were recruited from the Reserve Officers' Training Course (ROTC) cadets at a University in the southeast United States. The participants were recruited predominately from the junior and senior military science classes and/or Ranger Challenge team because of their physical training status and compliance with Army physical fitness standards. An informed consent was signed by each participant prior to participation in the study (see Appendix A).

Instrumentation

Height. The height of each participant was measured to the nearest millimeter using a SECA stadiometer (SECA; Hanover, MD). The same stadiometer was used throughout the study to reduce error. Participants took off their shoes and any headwear prior to being measured. Each participant stood, wearing undershirt, shorts or ACU trousers, and socks, with his feet parallel and together to ensure correct weight distribution during the height measurement.

Mass measurements. The mass of each participant and his boots was measured to the nearest 0.1 kilogram using a Health-O-Meter® Professional scale (Northbrook, IL). In order to reduce error, the same scale was used throughout the study. Each participant was measured while wearing an undershirt, shorts or ACU trousers, and socks. The mass of the cadet's boots was recorded separately. A second mass measurement for each participant, referred to as loaded mass, was taken with the cadet wearing his Army Combat Uniform (ACU's), boots, Kevlar helmet, 30 lb vest, and 35 lb rucksack.

Oxygen cost. Oxygen consumption was measured through open-circuit spirometry using an AEI Moxus metabolic cart (Bastrop, TX). The metabolic cart was calibrated according to manufacturer's instructions before beginning each test session. The metabolic cart was turned on for a minimum of 45-60 minutes prior to calibration. The Moxus was first calibrated to room air and then to a reference gas. Gas calibration was completed by setting the calibration gas regulators to 3 psi. The low calibration gas value for oxygen was 16.08%, while the high calibration was 20.93%. The low carbon dioxide value was 0.03%, and the high carbon dioxide value was 4.0%.

Flow and volume were calibrated by removing the mouthpiece from the breathing valve and making sure the saliva trap and black cap were tightly attached to the breathing valve. The instructions for pumping the calibration syringe were followed to complete calibration of the AEI Moxus metabolic cart.

Heart rate. Heart rate was measured through telemetry with a Polar T31 heart rate monitor (Warminster, PA).

Stride length. The average stride length was calculated for each participant using direct observation of video recorded during each condition. The video was attained with a Sony Handycam Camcorder with 16 GB internal memory. A large stop clock was attached to the rail of the treadmill so that time could simultaneously be recorded in the video footage during testing. For the purpose of this study, stride length was calculated by counting each time the left foot made contact with the treadmill and dividing into the total distance covered in the test.

Procedures

Permission was requested from the university Institutional Review Board (IRB). Once IRB approval was attained (see Appendix B), participants were recruited from the University ROTC attachment. Cadets were notified of their testing date and time a minimum of 1 week in advance. Prior to testing, cadets signed a consent form. The ROTC cadets also agreed to pre-test conditions which included: (a) no alcohol 24 hours prior to testing, (b) no caffeine or nicotine consumption 2 hours prior to testing, (c) maintenance of proper hydration a minimum of 48 hours prior to testing, and (d) obtaining a minimum of 7 hours of sleep the night before testing.

On arrival for testing, height, and body mass were measured and recorded on a data collection form (see Appendix C). The mass of each cadet's boots was measured and recorded separately. The cadet's loaded mass measurement was taken with the cadet wearing a 28.6 lb weighted vest, US Army approved uniform, and the 35 lb rucksack typically worn during tactical march. This US Army approved uniform consisted of the standard blouse, trousers, undershirt, belt, Kevlar helmet, identification tags (dog tags), and boots. The cadet's total loaded mass was the mass entered into the AEI Moxus metabolic cart software.

Torso loading. During testing, the participants wore a 28.6 lb weighted vest and a 35 lb rucksack. The weighted vest was used to simulate the standard medium-sized outer tactical Kevlar vest, without deltoid and axillary protectors (Knapik & Reynolds, 2010). In order to establish the precise mass of the weighted vest, bee-bees were added and evenly distributed throughout. The standard weight of a rucksack used during training marches at airborne school is 35 lbs ("Enlisted green platoon," 2009). Therefore, the rucksack carried during testing weighed 35 lbs. The same weighted vest and rucksack were used for all participants. The rucksack was pre-packed using the standard combat load in order to control for the packing and weight distribution of the rucksack. The contents of the rucksack was determined by the packing list given in the Airborne Enlisted Green Platoon Information Packet ("Enlisted green platoon," 2009) and recommendations of the University Army ROTC program (Appendix D). The contents of the rucksack were packed by an experienced 4th year cadet, according to the packing sequence recommended by the Army ROTC program (C/MAJ Duke, personal communication, September 19, 2013).

Speed. The 101st Airborne Division (Air Assault) requires that each cadet complete the Division Standards of a 12 mile tactical foot march in 4 hours ("Basic standards of the airborne," 2011), which averages to be a 3.0 mph pace. A pace above and below the average speed for successful completion of the 12 mile march in 4 hours were selected for the test protocol. Testing speeds included of 2.5, 3.0, and 3.5 mph. The order of the speeds were randomized and the order of the testing sessions was counterbalanced for each participant. There were 2 separate test condition days (shuffle and walk), with 3 test scenario speeds (2.5, 3.0, and 3.5 mph) being completed on each day. Each participant waited a minimum of 48 hours prior to completing a second test day. No participant began the next test scenario until he had rested a minimum of 5 minutes, HR was below 120 bpm, and he reported feeling ready to begin the next test scenario (Hardin, van den Bogert, & Hamill, 2004).

Economy testing. Economy testing was conducted Monday through Thursday between the hours of 5:30 am-8:00 am. Any missed test sessions were made up on

Friday's between the hours of 5:30 am-8:00 am. Each participant came in for 3 test days. The first test day was an orientation, where the cadet was introduced to the study parameters and became comfortable moving on the treadmill while wearing gas collection equipment. During the subsequent test days, the cadet was assigned one of two test conditions, walking or airborne shuffle. Data were collected on 2 separate days to avoid any fatigue effects. Economy testing was completed at one of 3 speeds (2.5, 3.0, 3.5 mph) for both walking and airborne shuffle. Prior to beginning each economy tests, five minutes of standing on the treadmill was required to measure baseline oxygen values. Following baseline oxygen consumption measures, the economy test began and included 5 additional minutes of oxygen consumption measures at the assigned condition and speed. Of the total 5 minute economy test, only the last 2 minutes of oxygen consumption were averaged for analysis (Abe et al., 2008; Abe, Yanagawa, & Niihata, 2004; Keren, Epstein, Magazanik, & Sohar, 1981; Sawyer et al., 2010; Stuempfle, Drury, & Wilson, 2004).

Heart rate. A heart rate monitor was placed on the participant prior to beginning each test condition and heart rate was recorded during the entirety of the tests. Only the last 2 minutes of economy testing were averaged and used to determine if there was a significant difference in HR while shuffling or walking at the same speeds.

Respiratory exchange ratio (RER). Respiratory exchange ratio was determined from analysis of oxygen consumption measures. The RER from the last 2 minutes of oxygen consumption were averaged and used for data analysis.

Data Analysis

Data analyses were performed using Statistical Package for the Social Sciences (SPSS version 20.0). Descriptive statistics were computed for all variables. A 2 (mode), x 3 (speed) Analysis of Variance (ANOVA) for repeated measures was used to compare oxygen cost, HR and RER for mode and each speed. One-way repeated measures ANOVAs were used as post-hoc tests to compare mode on each speed for oxygen cost, HR, and RER. Stride length at the time of relevant oxygen consumption measures (4^{th} and 5^{th} minutes of testing) were used to assess the stride frequency of the airborne shuffle. The numbers of right leg strides were divided by the total distance covered during the 4^{th} and 5^{th} minutes. A 2 (mode), x 3 (speed) ANOVA for repeated measures was used to compare stride length for mode and each speed. A one-way repeated measures ANOVA was used as post-hoc test to compare mode on each speed for stride length. The alpha level was set at $p > .05$.

CHAPTER IV

RESULTS

The sample contained 20 male ROTC cadets including 1 first year cadet, 11 third year cadets, and 8 fourth year cadets. Descriptive characteristics of the sample are presented in Table 2. Of the 20 participants, 6 cadets were participants in the Ranger Challenge competition for the 2013-2014 academic year. The 2 (mode), x 3 (speed) ANOVAs for repeated measures found the models were significant for oxygen cost ($p < .001$), HR ($p < .001$), and RER ($p < .001$; see Table 3). Post-hoc comparisons revealed that the oxygen cost of shuffling was significantly higher than the oxygen cost of walking at 2.5 mph, F (1,19) = 115.56, $p < .001$, $\eta^2 = .86$; at 3.0 mph, F (1,19) = 112.60, $p < .001$, $\eta^2 = .86$; and at 3.5 mph, F (1,19) = 49.94, $p < .001$, $\eta^2 = .72$. Heart rate while shuffling was significantly higher than HR while walking at 2.5 mph, F (1,19) = 83.02, $p < .001$, $\eta^2 = .81$; at 3.0 mph, F (1,19) = 110.07, $p < .001$, $\eta^2 = .85$; and at 3.5 mph, F (1,19) = 113.89, $p < .001$, $\eta^2 = .86$. Lastly, the RER while airborne shuffling was significantly higher than the RER while walking at 2.5 mph, F (1,19) = 19.58, $p < .001$, $\eta^2 = .51$; at 3.0 mph, F (1,19) = 31.43, $p < .001$, $\eta^2 = .62$; and at 3.5 mph, F (1,19) = 19.13, $p < .001$, $\eta^2 = .50$.

The results of the stride length analysis are presented in Table 4. The 2 (mode), x 3 (speed) ANOVA for repeated measures found the models for stride length was significant ($p < .001$).Using the outlier labeling rule (Hoaglin, Iglewicz, & Tukey, 1986) two statistical outliers were found and two cadets were dropped from the 2.5 mph stride length analysis. There was a statistically significant increase in stride length as speed increased for both walking, F (2,18) = 284.52, p < .001, η^2 = .97, and shuffling, F (2,18) = 151.35, p < .001, η^2 = .94. Average stride length while shuffling at 2.5 mph was significantly shorter than the stride length while walking at 2.5 mph, F (1,19) = 70.21, p < .001, η^2 = .79. Average stride length while shuffling at 3.0 mph was significantly shorter than the stride length while walking at 3.0 mph, F (1,19) = 505.98, p < .001, η^2 = .96. The stride length while shuffling at 3.5 mph was significantly shorter than the stride length while walking at 3.5 mph, F (1,19) = 438.05, p < .001, η^2 = .96.

Table 2

Descriptive Characteristic of Participants (N = 20)

Variable	*M* (± *SD*)
Age (years)	22.4 (± 3.2)
Height (cm)	177.5 (± 7.6)
Body mass (kg)	79.29 (± 10.67)
Load mass (kg)	112.32 (± 10.81)

Note. Loaded mass = body mass + gear (weighted vest, rucksack, Army Combat Uniform).

Table 3

Dependent Variables of Walking and the Airborne Shuffle (N = 20)

Speed (mph)	Walking *M* (± *SD*)	Shuffling *M* (± *SD*)
O_2 consumption (ml·kg·min^{-1})		
2.5	10.66 (± 0.93)	15.17 (± 1.79) *
3.0	12.38 (± 1.05)	17.13 (± 1.83) *
3.5	15.09 (± 2.32)	19.67 (± 1.95) *
HR (bpm)		
2.5	103 (± 14)	124 (± 15) *
3.0	110 (± 15)	131 (± 15) *
3.5	122 (± 16)	142 (± 15) *
RER		
2.5	0.81 (± 0.06)	0.87 (± 0.04) *
3.0	0.83 (± 0.05)	0.89 (± 0.05) *
3.5	0.87 (± 0.05)	0.93 (± 0.05) *

Note. O_2 = oxygen; HR = heart rate; RER = respiratory exchange ratio; * = Significantly different from walking at $p < .001$.

Table 4

Stride Length of Walking and the Airborne Shuffle

Speed (mph)	Walking *M* (± *SD*)	Shuffling *M* (± *SD*)
2.5 (*n* = 18)	2.2 (± 0.1)	1.6 (± 0.3) *
3.0 (*n* = 20)	2.4 (± 0.1)	1.8 (± 0.1) *
3.5 (*n* = 20)	2.6 (± 0.0)	2.0 (± 0.1) *

Note. * = Significantly different from walking at $p < .001$.

CHAPTER V

DISCUSSION

The purpose of this study was to compare oxygen cost, HR, RER, and stride length during the airborne shuffle to a standard walk at 2.5 mph, 3.0 mph, and 3.5 mph while torso loaded. Current data revealed that oxygen cost, HR, and RER were significantly higher during the airborne shuffle compared to standard walking at all speeds. Additionally, stride length during the airborne shuffle was found to be significantly shorter compared to the stride length during standard walking at all speeds.

According to personal communications with US Army personnel, a rationale for using the airborne shuffle is to reduce stress on the joints of the body while moving quickly with a loaded rucksack. The term airborne shuffle is a term used in military jargon, and to our knowledge, not defined or explained in official US Army literature or documents. This study provided an opportunity to describe and possibly define the airborne shuffle. The current study demonstrated that the airborne shuffle was a gait pattern characterized by shorter stride length and a higher vertical displacement than walking at the same speed. The shorter stride length and increased vertical displacement characterizes the airborne shuffle as an altered gait pattern.

Several studies have shown that altering gait patterns can increase physiological response, including oxygen cost (Egbuonu, Cavanagh, & Miller, 1990; Martin & Morgan, 1992; Tseh et al., 2008). The increased vertical displacement could be an explanation for the increased oxygen cost, HR, and RER, during the airborne shuffle. Egbuonu et al.

(1990) documented that female distance runners who ran with a greater vertical displacement, had an increased oxygen uptake. Tseh et al. (2008) examined the impact of different running gait patterns including standard running, running with clasped hands behind the back, running with clasped hands on top of the head, and running with exaggerated vertical displacement. Participants running with exaggerated vertical displacement yielded the highest oxygen cost (Tseh et al., 2008). Based on the aforementioned studies, it is possible that an increase in vertical displacement contributed to the increased energy cost of the airborne shuffle.

Another factor potentially contributing to the higher oxygen cost and HR of the airborne shuffle was the shortened stride length. Scott and Christie (2004) conducted a study to identify the “optimal” speed-load combination to reduce physical stress. Stride length varied amongst the 3 conditions of speed-load combinations, with the heaviest load resulting in more “mincing” steps. It was also noted that it took the shorter soldiers (161.5 cm) more steps to travel the same distance in the same time frame compared to taller soldiers (186.4 cm). The effect of a shorter stride length on energy cost was considered important because more steps taken equated to a higher energy cost. This same phenomenon can be applied to the current research. When performing the airborne shuffle, cadets used a shorter stride length compared to a standard walk at the same speed. The shorter stride length ultimately yielded higher oxygen cost and HR.

According to Martin and Morgan (1992), the aerobic demand of walking or running at a given speed increased curvalinearly as stride length was lengthened or shortened from a freely chosen stride length. Near the optimal combination of stride length and rate, economy is not necessarily sensitive to small alterations in stride length or rate. When either variable (stride length or rate) are considerably altered from the optimal combination, aerobic demand significantly increases (Martin & Morgan, 1992). In the present study, the cadets had a significantly shorter stride length in the airborne shuffle when compared to standard walking at all speeds likely contributing to the increased oxygen cost and HR at each speed. The oxygen cost and HR is an important physiological response for a soldier as it impacts their performance on marches.

In some cases (mission or school-specific) it is necessary for military personnel to march, while torso loaded, for multiple miles and/or multiple hours. The speeds used in the current study were based on the 101st Airborne Division standard for tactical foot marches which is a 12 mile march in 4 hours with a loaded MOLLE pack ("Basic standards of the airborne," 2011). During these long marches it is important to choose gait patterns that are most economical. A possible consequence of choosing gait patterns that are not the most economical is the depletion of muscle glycogen which is a signal of fatigue (Lambert, Gibson, & Noakes, 2005). Measures of fuel utilization could indicate whether specific gait patterns are more likely to deplete glycogen during prolonged marches. The respiratory exchange ratio approximates the type of nutrient used during physical activity to produce energy. Prolonged periods of time that are closer to an RER of 1.0 promote depletion of glycogen stores because carbohydrates are the primary fuel source. In the current study, the RER of the airborne shuffle was significantly higher than the RER of walking at all speeds (see Table 3). The most notable RER difference was at the highest speed (3.5 mph) when there was an RER of .87 during walking and an RER of .93 during the airborne shuffle. Current data suggests that the RER of performing the airborne shuffle is consistently higher at all speeds and would more likely exhaust glycogen stores which, in turn, would promote fatigue. Despite the findings that indicate the airborne shuffle has a higher physiological cost at all speeds, cadets did not perceive the airborne shuffle as more difficult at all speeds.

Further studies are warranted to examine if there is a most economical speed for use of the airborne shuffle. Lactate measures in conjunction with oxygen cost, HR, and RER could provide a measure of either aerobic or anaerobic demands at higher speeds to determine at what point the airborne shuffle is no longer physiologically maintainable. The present study only included speeds of 2.5 mph, 3.0 mph, and 3.5 mph. A comparison of the airborne shuffle at higher speeds is needed to examine whether the findings of this study will also occur at higher speeds. Future studies also need to include objective measures of vertical displacement when comparing the airborne shuffle to walking. Lastly, there is a lack of information on whether the airborne shuffle reduces the physical stresses of carrying a torso load on the joints of the body. Studies should be performed to investigate this claim.

To our knowledge, there is a lack of research that has examined physiological and biomechanical variables during altered gait patterns with torso loading. Therefore, this study is unique because oxygen costs, HRs, RERs, and stride lengths of the airborne shuffle (an altered gait pattern) were compared to standard walking. The results from this study show that using the airborne shuffle, while loaded, at speeds of 2.5 mph, 3.0 mph, and 3.5 mph, are less economical than walking and may induce fatigue in a shorter period of time.

Practical Applications

Results from this study enabled a better understanding of the most economical method for marching while carrying a 35 lb rucksack, which is the weight of a standard US Army combat load. The findings of this study indicate that using the airborne shuffle, while carrying a standard combat load, at speeds of 2.5 mph, 3.0 mph, and 3.5 mph is not as economical as standard walking at these same speeds. The airborne shuffle elicited a higher RER compared to a walk at each speed. Based off the evaluation of the current RER findings alone, it can be concluded that the airborne shuffle is more likely to induce fatigue more quickly than a walk. A necessity of US Army personnel is to avoid fatigue while transporting equipment across a distance on foot. Upon destination arrival, the soldier is then expected to perform military tasks and return to safety before exhaustion impedes the mission or survival. When selecting a march method, the physiological expense required of the movement should be considered. Current data indicate walking is a more economical means of foot transportation than the airborne shuffle, and may be a better mode of transportation if minimizing fatigue is important to mission success.

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APPENDIX A

Informed Consent Form

MTSU
IRB Approved
Date: 8/23/13

Principal Investigator: Amanda N. Brenes
Study Title: The effect of the airborne shuffle on oxygen cost of Army ROTC participants
Institution: Middle Tennessee State University

Name of participant: ____ Age: ________

The following information is provided to inform you about the research project and your participation in it. Please read this form carefully and feel free to ask any questions you may have about this study and the information given below. You will be given an opportunity to ask questions, and your questions will be answered. Also, you will be given a copy of this consent form.

Your participation in this research study is voluntary. You are also free to withdraw from this study at any time. In the event new information becomes available that may affect the risks or benefits associated with this research study or your willingness to participate in it, you will be notified so that you can make an informed decision whether or not to continue your participation in this study.

For additional information about giving consent or your rights as a participant in this study, please feel free to contact the MTSU Office of Compliance at (615) 494-8918.

1. **Purpose of the study:**
   The purpose of this study is to measure the oxygen cost of the airborne shuffle while loaded with a 35 lbs rucksack.

2. **Description of procedures to be followed and approximate duration of the study:**
   You will be asked to complete 6 test scenarios on two separate test days. Three test scenarios will be completed in one test session. Each test session will contain a combination of walking and shuffling at a speed of 2.5, 3.0, and 3.5 miles per hour on a treadmill while torso loaded with a standard 35 lb rucksack. Participants will wear their Army Combat Uniform, Kevlar helmet, a 30 lb weighted vest, and will carry an imitation weapon in the ready position. Each test scenario will last 6 minutes. Oxygen cost will be measured using an AEI Moxus metabolic cart. You will be connected to the metabolic cart for the entirety of the test session.

3. **Expected costs:**
   None.

4. **Description of the discomforts, inconveniences, and/or risks that can be reasonably expected as a result of participation in this study:**
   As with any exercise, minimal discomfort may be experienced.

5. **Compensation in case of study-related injury:**
   MTSU will not provide compensation in the case of study related injury.

6. **Anticipated benefits from this study:**

a) The potential benefits to science and humankind that may result from this study are giving a better understanding of the most economical means of movement while torso loaded with a rucksack.

b) The potential benefits to you from this study are you will gain personal information pertaining to the most beneficial means of movement for you while carrying the standard combat load of 35 lbs.

7. **Alternative treatments available:**
   None.

8. **Compensation for participation:**
   Participants will be dismissed from mandatory Physical Training sessions on the day of testing. Testing will substitute as Physical Training for that day. A copy of individual information evaluated will be given to the participant and any questions will be answered.

Middle Tennessee State University Institutional Review Board
Informed Consent Document for Research

9. **Circumstances under which the Principal Investigator may withdraw you from study participation:** If the participant has used alcohol 24 hours prior to testing, has consumed caffeine or nicotine 2 hours prior to testing, is not properly hydrated for a minimum of 48 hours prior to testing, did not obtain a minimum of 7 hours of sleep the night before testing, is not properly dressed, is sick, or violates any parameter that could hamper accuracy of data collected.

10. **What happens if you choose to withdraw from study participation:** There will be no penalty for withdraw at any time during the study.

11. **Contact Information.** If you should have any questions about this research study or possible injury, please feel free to contact Amanda Brenes at (910) 554-5345 or my Faculty Advisor, Dr. John Coons at 615-494-7973.

12. **Confidentiality.** All efforts, within reason, will be made to keep the personal information in your research record private but total privacy cannot be promised. Your information may be shared with MTSU or the government, such as the Middle Tennessee State University Institutional Review Board, Federal Government Office for Human Research Protections, if you or someone else is in danger or if we are required to do so by law.

13. **STATEMENT BY PERSON AGREEING TO PARTICIPATE IN THIS STUDY**
I have read this informed consent document and the material contained in it has been explained to me verbally. I understand each part of the document, all my questions have been answered, and I freely and voluntarily choose to participate in this study.

Date　　　　　　Signature of patient/volunteer

Consent obtained by:

Date　　　　　　Signature

Printed Name and Title

APPENDIX B

University Institutional Review Board Approval

August 23, 2013

Amanda N. Brenes
CC: Dr. John Coons
Protocol Title: **THE EFFECT OF THE AIRBORNE SHUFFLE ON OXYGEN COST, WHILE TORSO LOADED**
Protocol Number: 14-023

Dear Investigator(s),

The MTSU Institutional Review Board or its representative has reviewed the research proposal identified above. The MTSU IRB or its representative has determined that the study meets the criteria for approval under 45 CFR 46.110 and 21 CFR 56.110, and you have satisfactorily addressed all of the points brought up during the review.

Approval is granted for one (1) year from the date of this letter for **30** participants. Please use the version of the consent form with the compliance office stamp on it that will be emailed to you shortly.

Please note that any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918. Any change to the protocol must be submitted to the IRB before implementing this change.

You will need to submit an end-of-project report to the Office of Compliance upon completion of your research. Complete research means that you have finished collecting and analyzing data. Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date. Please allow time for review and requested revisions. Failure to submit a Progress Report and request for continuation will automatically result in cancellation of your research study. Therefore, you will NOT be able to use any data and/or collect any data.

According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to complete training (there is no need to include training certificates in your correspondence with the IRB). If you add researchers to an approved project, please forward an updated list of researchers to the Office of Compliance (compliance@mtsu.edu) before they begin to work on the project.

All paperwork, including consent forms, needs to be given to the faculty advisor for storage. All research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion and then destroyed in a manner that maintains confidentiality and anonymity.

Sincerely,

William Langston
Chair, MTSU Institutional Review Board

APPENDIX C

Data Collection Form

Airborne Shuffle Demographics Sheet

ID number: _______________ Age: _______________ Height: ________________

MS Year: ________________ Ranger Challenge: Yes No

TEST SESSION 1:

Date: ________________

Body mass	
Boot mass	
Body mass + Torso Load	

Condition Scenario: SHUFFLE

RPE: Test 1 Speed: 2.5 mph	
Minute 4	
Minute 5	

RPE: Test 2 Speed: 3.0 mph	
Minute 4	
Minute 5	

RPE: Test 1 Speed: 3.5 mph	
Minute 4	
Minute 5	

TEST SESSION 2:

Date: ________________

Body mass	
Boot mass	
Body mass + Torso Load	

Condition Scenario: WALK

RPE: Test 1 Speed: 3.0 mph	
Minute 4	
Minute 5	

RPE: Test 2 Speed: 3.5 mph	
Minute 4	
Minute 5	

RPE: Test 1 Speed: 2.5 mph	
Minute 4	
Minute 5	

APPENDIX D

Rucksack Packing List

Rucksack Packing List

Item	Quantity
Poncho	1
Wet Weather Bag	1
w/w Trousers Size Medium	1
Parka Cold Weather Size Large/Regular	1
ACU Jacket Size Medium/Regular	1
ACU Pants Size Medium/Regular	1
Tan T-Shirt Size Medium	1
MOLLE Set Complete	1
Canteen	2
Canteen Cup	1

Note. All items were checked out from the MTSU US Army ROTC program.