THE TACTICAL MARCH: QUANTIFICATION OF THE GAIT AND ECONOMY OF THE AIRBORNE SHUFFLE IN TORSO LOADED U.S. SOLDIERS

by

Casey B. Clark

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Dissertation Committee:

Dr. Jennifer L. Caputo, Chair

Dr. John M. Coons

Dr. Don W. Morgan

Dr. Dana K. Fuller

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ABSTRACT

During torso loaded tactical marching U.S. soldiers sometimes utilize the airborne shuffle, which is a purposeful manipulation of the walking gait characterized by a shortened stride length. This dissertation was designed to describe the gait characteristics and compare physiological between walking and the shuffle while torso loaded in U.S. Army soldiers ($N = 11$). In the first study, the gait characteristics during torso-loaded and unloaded walking and shuffling at 3.0 mph were compared. Differences in speed and economy of the preferred walking speed (PWS) and the preferred shuffle speed (PSS) were evaluated in the second study. The oxygen cost (VO_2) at the PSS and the most economical shuffle speed (ESS) were assessed in the final study.

Stride length ($p < .001$), stance time ($p < .001$), swing time ($p < .001$), single support time ($p < .001$), and double support time ($p < .001$) were shorter while stride frequency ($p < .001$) was greater during the shuffle than while walking at 3.0 mph. Swing time ($p = .02$) was shorter and double support time ($p < .05$) was longer when loaded. The preferred speed ($p = .04$), VO_2 ($p = .002$), heart rate (HR; $p = .002$), respiratory exchange ratio (RER; $p = .001$), V_e ($p = .002$), and rating of perceived exertion (RPE; $p = .002$) were higher at the PSS than at the PWS. The VO_2 was lower at the ESS than at the PSS ($p = .005$), but speed ($p = .27$), HR ($p = .17$), RER ($p = .87$), ventilation ($p = .46$), and RPE ($p = .36$) were not different.

Overall, the gait characteristics of the shuffle were significantly different from those of a walking gait. The shuffle was less economical at preferred speeds than a walking gait, and the economy at the PSS and at the ESS were different. While there may

be benefits to using the shuffle for decreasing stress on the lower limbs, a walking gait should be prioritized over the shuffle during torso loaded tactical marching as the shuffle is less economical and is perceived as more difficult compared to walking.

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LIST OF ABBREVIATIONS

ACH =	Advanced Combat Helmet
ACU =	Army Combat Uniform
AIT =	Advanced Individual Training
APFU =	Army Physical Fitness Uniform
BCT =	Basic Combat Training
DST =	Double Support Time
ESS =	Most Economical Shuffle Speed
FCSL =	Freely Chosen Stride Length
FM =	Field Manual (FM-21-18)
FT =	Flight Time
HR =	Heart Rate
IBA =	Interceptor Body Armor
MOLLE =	Modular Lightweight Load-carrying Equipment
OSS =	Optimal Shuffle Speed
OWS =	Optimal Walking Speed
%BM =	Percent Body Mass
%LBM =	Percent Lean Body Mass
PSS =	Preferred Shuffle Speed
PWS =	Preferred Walking Speed
RER =	Respiratory Exchange Ratio
ROTC =	Reserve Officer Training Corps

RPE =	Rating of Perceived Exertion
SF =	Stride Frequency
SL =	Stride Length
SST =	Single Support Time
ST =	Stance Time
SW =	Swing Time

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CHAPTER I

DISSERTATION INTRODUCTION

Soldiers have been required to physically transport equipment throughout history. These combat and approach loads carried by soldiers have increased over time and are now greater than at any other point in history (Knapik, Reynolds, & Harman, 2004). Advances in technology such as armored troop carriers and other vehicles that facilitate troop and supply movement, lightweight components in packs and equipment, and a focus on marksmanship to decrease ammunition carriage needs, should reasonably be expected to decrease loads carried by soldiers. However, the modern urban battlefield necessitates that soldiers still physically transport their personal equipment. Consequently, United States Army (U.S. Army) soldiers are often evaluated on their ability to perform a tactical march under torso load in training schools such as basic combat training (BCT), Air Assault, and Reserve Officer Training Corps (ROTC) programs (U.S. Department of the Army, 2011).

There is an increased potential for lower body musculoskeletal injuries while carrying heavy loads during tactical marches (Kaufman, Brodine, & Shaffer, 2001; Liu, 2007; Ricciardi, Deuster, & Talbot, 2008; Seay, Fellin, Sauer, Frykman, & Bensel, 2014; Songer & LaPorte, 2000; Warr et al., 2015) particularly among recruits and infantry soldiers (Warr et al., 2015). For this reason, running and overstriding during torso-loaded tactical marches are discouraged (U.S. Department of the Army, 1990). In normal human walking, changes in stride length from the FCSL can alter the economy of movement as measured using oxygen consumption (Morgan et al., 1994; Morgan, Martin, & Krahenbuhl, 1989). However, to compensate for the load carried while walking or marching, soldiers may alter their gait. Grenier et al. (2012) have documented decreases in step length with increased torso load in recently retired French Foreign Legion infantrymen. There is also evidence that decreasing stride length or increasing stride frequency may reduce the stress placed on the metatarsal bones during dorsiflexion of the foot at toe-off during loaded walking (Birrell & Haslam, 2009; Kinoshita, 1985). In the Army, soldiers often adopt a gait pattern that is commonly referred to as the airborne shuffle during tactical marches. The airborne shuffle is sometimes employed to maintain a required speed during a tactical march, while avoiding over-striding. While not yet characterized in the literature, the airborne shuffle is a purposeful alteration in natural gait pattern that is sometimes used during loaded ambulation.

Purpose of Studies

Three studies concerning the airborne shuffle were conducted for this dissertation. The first study was designed to quantify the gait characteristics of the airborne shuffle, both under torso loaded and unloaded conditions, and compare these characteristics to those of a walking gait under the same conditions. The second study was designed to determine the average preferred walking speed and average preferred airborne shuffle speed while torso loaded and test for differences between the two. The third study was designed to determine the optimal airborne shuffle speed and test the economy of movement at this speed to the economy of movement at the preferred airborne shuffle speed.

Significance of Studies

It is important to understand the gait characteristics of the airborne shuffle as well as the effect it has on economy of movement. Defining the gait characteristics of the airborne shuffle provided a basis for understanding the physiological responses to this type of gait in the subsequent studies. If there is significant increase in aerobic demand of ambulation during use of the airborne shuffle, it is possible that any potential benefits associated with a decreased stride length may be outweighed by the increase in aerobic demand. Together, these studies provided a foundation for determining the usefulness of the airborne shuffle as a type of movement during a tactical march compared to a standard walking gait.

CHAPTER II

REVIEW OF THE LITERATURE

United States Army (U.S. Army) soldiers are often evaluated on their ability to perform a tactical march under torso load in training schools such as basic combat training (BCT), Air Assault, and Reserve Officer Training Corps (ROTC) programs (U.S. Department of the Army, 2011). Advances in technology such as armored troop carriers and other vehicles that facilitate troop and supply movement, lightweight components in packs and equipment, and a focus on marksmanship to decrease ammunition carriage needs, should reasonably be expected to decrease loads carried by soldiers. However, the modern urban battlefield necessitates that soldiers still physically transport their personal equipment. In fact, combat loads carried by soldiers have increased over time and these loads are now greater than at any other point in history (Knapik et al., 2004).

There is an increased potential for lower body musculoskeletal injuries while carrying heavy loads during tactical marches (Kaufman et al., 2001; Liu, 2007; Ricciardi et al., 2008; Seay et al., 2014; Songer & LaPorte, 2000; Warr et al., 2015) particularly among recruits and infantry soldiers (Warr et al., 2015). For this reason, running and over-striding during torso-loaded tactical marches are discouraged (US Department of the Army, 1990). An alternative gait that is being used by soldiers to increase speed during marches is the airborne shuffle. The airborne shuffle resembles a trot, but it is not well characterized in the literature.

In order to optimize performance and minimize injury during torso loaded tactical marches, it is important to understand how load carriage and different patterns of ambulation affect factors such as the economy of ambulation and gait mechanics. These topics will be highlighted in the following review.

Tactical Marches

In BCT and advanced individual training (AIT), as well as other Army schools such as Air Assault, Airborne, Ranger, and Special Operations, soldiers are evaluated on their ability to perform tactical marches under torso load within a specified time frame. Distances in BCT initially start at 4 km with minimal load and progressively increase throughout training duration to 15km with heavier loads. Similarly, the 101st Airborne Division mandates a standard rucksack load of 35-40 lbs during tactical marches and a completion distance and time of 12 miles in 4 hours (U.S. Department of the Army, 2011).

According to the Army Field Manual 21-18 (FM 21-18), carried loads should not exceed 48 lbs for fighting loads or 72 lbs for approach loads. For instance, the 160th Special Operations Aviation Regiment requires a standard rucksack load of 35-40 lbs during tactical marches (U.S. Department of the Army, 2009). However, the total load which is carried often exceeds this weight due to additional equipment beyond that accounted for by the rucksack and its contents. Soldiers may also wear or carry an advanced combat helmet (ACH; 3 lbs), interceptor body armor without attachments (IBA; 16.4 lbs), and a weapon system (7 ~ 27 lbs). Additionally, all ammunition, water, and/or equipment attached to the modular webbing of various assault vests contribute to the total load. Based on these additional components, it is clear that the load carried by soldiers can easily exceed those used in Army schools and those recommended by Army manuals such as FM 21-18.

To compensate for the load carried while walking or marching, soldiers may alter their gait. Grenier et al. (2012) have documented decreases in step length with increased torso load in recently retired French Foreign Legion infantrymen. There is also evidence that decreasing stride length or increasing stride frequency may reduce the stress placed on the metatarsal bones during dorsiflexion of the foot at toe-off during loaded walking (Kinoshita, 1985). In the Army, soldiers often adopt a gait pattern that is commonly referred to as the airborne shuffle during tactical marches. While not yet characterized in the literature, the airborne shuffle is a purposeful alteration in natural gait pattern that is sometimes used during loaded ambulation.

Airborne Shuffle

Similar to a trot, there is a style of movement used throughout the Army that is referred to as the airborne shuffle. There is no clear explanation of the characteristics of the airborne shuffle and only limited information is available on how it affects metabolic economy of movement. Based on the limited data from a recent study by Brenes, Caputo, Clark, Wehrly, and Coons, (2015), it appears that the airborne shuffle is a purposeful manipulation of gait by soldiers to decrease stride length while maintaining movement speed.

Running and over-striding are discouraged during torso-loaded tactical marches because of increased potential for lower-extremity injury (Seay et al., 2014; U.S.

Department of the Army, 1990). Some commanders encourage the use of the airborne shuffle because of a belief that it may reduce knee strain (Brenes et al., 2015). While this belief has yet to be supported by research, there is some evidence that a decrease in stride length with a concomitant increase in double support time, when torso loaded, may decrease internal loads on the joints of the lower limbs (Birrell & Haslam, 2009).

Reduction of the incidence of lower limb injury is a significant concern as lower-extremity injuries are some of the most frequently occurring noncombat related musculoskeletal injuries (Kaufman et al., 2001; Liu, 2007; Ricciardi et al., 2008; Songer & LaPorte, 2000; Warr et al., 2015), particularly among recruits and infantry soldiers (Warr et al., 2015). However, potential reductions in the rate of injury must be weighed against alterations in economy of movement. In general, guidelines set forth in FM 21-18 (U.S. Department of the Army, 1990) are based on optimal speeds and loads in association with time to exhaustion. Therefore, it is also paramount to investigate changes in the metabolic economy of movement associated with deliberate alterations in walking gait under torso load associated with the airborne shuffle. Currently, there is a lack of quantitative information evaluating the characteristics of the airborne shuffle and a lack of research comparing the airborne shuffle to normal human walking.

Normal Human Walking

Walking can be described as a cyclic pattern of movements in which the erect, moving body is supported by one leg and then the other (Rose & Gamble, 2006). Due to the inherent variation in individuals' gait, it is necessary to evaluate and average the spatiotemporal characteristics of human walking to describe the effect of any abnormal condition on a normal walking gait. A simple way to evaluate human walking is by measuring stride length or stride frequency. Stride length is the distance from foot contact on one limb until second ipsilateral foot contact (Hamill & Knutzen, 2009) and stride frequency is defined as the number of strides taken per minute.

A gait cycle is the period of time during which regularly occurring events associated with ambulation occur (Rose & Gamble, 2006). In human ambulation, a gait cycle is broken down into two major phases, stance and swing (Agostini, Balestra, & Knaflitz, 2014). In the stance phase, the leg is in contact with the ground and comprises the period between foot strike and ipsilateral foot off. The leg advances through the air during the swing phase and is measured as the time-period from the start of foot-off until ipsilateral foot strike (Rose & Gamble, 2006; Vidhya, Saranya, & Poonguzhali, 2014). These major phases are then further divided into periods of movement during the respective phase. The stance phase averages 62% of the gait cycle and is comprised of three periods: initial double limb support, single limb support, and second double limb support. The swing phase of a gait cycle averages 38% of the cycle and is also comprised of three periods: initial swing, mid swing, and terminal swing (Rose & Gamble, 2006).

Foot strike is a commonly measured characteristic of human gait (Mercer & Horsch, 2015; Reuterbories, Spaich, Larsen, & Andersen, 2010; Zhang, Ogata, Yozu, & Haga, 2013). The term foot strike is used, rather than heel strike, because an altered walking gait may not elicit a heel-first foot strike and similar reasoning applies to the term foot off rather than toe off (Rose & Gamble, 2006). Similarly, the same consideration should be made for human walking under load, particularly in the case of this study, as the airborne shuffle is a purposeful manipulation of gait which may not elicit a heel-first strike pattern.

Measurement of stride length and stride frequency are basic methods for determining changes in gait associated with human ambulation. Alterations in stride length or stride frequency from an individual's normal, or preferred, stride length or frequency, can alter the physiological response to ambulation. Economy of movement, measured through oxygen consumption, can provide information about how these gait alterations affect energy cost.

Economy of Walking

The economy of walking is defined as the aerobic demand of walking at a given submaximal speed, expressed relative to body mass (Morgan et al., 1989). An individual who requires more oxygen per unit body mass to walk a given distance is less economical compared to a person who consumes less oxygen per unit body mass (Waters, Lunsford, Perry, & Byrd, 1988). The economy of human walking decreases with changes in stride length away from freely-chosen stride length (FCSL; Morgan et al., 1994; Morgan et al., 1989; Rose & Gamble, 2006). An individual's naturally occurring stride length at a given speed is typically not significantly different from the most economical stride length in race walking and running (Morgan et al., 1994; Morgan & Martin, 1986; Morgan et al., 1989). With deviations above or below FCSL, the aerobic demand of walking increases in a curvilinear fashion (Morgan et al., 1994; Morgan et al., 1989), with a greater increase in oxygen consumption when stride length is increased beyond FCSL (Morgan et al., 1994).

The alterations in the economy of movement associated with changes in stride length may have implications during the airborne shuffle. With a shorter stride length, it is not surprising that the airborne shuffle, while torso-loaded, was significantly less economical than walking while torso-loaded at 2.5, 3.0, and 3.5 mph (Brenes et al., 2005). However, there is still a lack of research investigating overall gait characteristics and the most economical speed of the airborne shuffle.

The bulk of the literature investigating load carriage in military populations has focused on walking conditions with changes in load mass or load positioning while other research has focused on how speed and load affect the economy of bipedal ambulation and gait. Before investigating alternative forms of gait while under load, it is critical to first understand how the human body responds to changes in load conditions and to changes in gait while torso-loaded as compared to normal human walking.

Torso Loading

A primary focus in the literature regarding load carriage is the metabolic demand of carrying a given load. Oxygen consumption is often linked to time to exhaustion when performing load carriage tasks. Research also shows that rating of perceived exertion (RPE), heart rate, and ventilation are also altered in response to increases in load mass and load position.

Load Mass

In human walking, total weight moved highly correlates with energy expenditure (Rose & Gamble, 2006). The aerobic demand of walking is higher during load carriage when compared to walking without load (Grenier et al., 2012; Legg & Mahanty, 1986; Quesada, Mengelkoch, Hale, & Simon, 2000). Generally, a linear increase in oxygen uptake occurs as load increases (Borghols, Dresen, & Hollander, 1978) even when walking speed is constant (Beekley, Alt, Buckley, Duffey, & Crowder, 2007). Conversely, a simple increase in load carriage while standing has little or no effect on oxygen uptake (Borghols et al., 1978) indicating that there is little or no change in the activation of postural muscles when supporting a load at rest.

In the literature, loads are typically standardized relative to body mass (Beekley et al., 2007; Quesada et al., 2000), in order to make appropriate comparisons of data among participants of varying sizes. Indeed, loads that are not standardized to body mass can elicit differing physiological results for individuals of different body sizes and result in a greater aerobic demand at a given load for a smaller individual than for a larger individual. In previous load carriage research involving military populations, loads used have been based on percent body mass (%BM) and tested in 15% increments (0%, 15%, 30%; Quesada et al., 2000). However, some researchers have used heavier loads (30%, 50%, and 70% of lean body mass (%LBM) (Beekley et al., 2007) than those used by Quesada et al. (2000) and observed similar increases in oxygen consumption. With an M83 assault vest, which distributes load evenly across the front and back of the torso, oxygen consumption is 6 $ml \cdot kg^{-1} \cdot min^{-1}$ greater than during an unloaded condition even when loaded with relatively light weight (8kg; Coombes & Kingwell, 2005). Alternately, it is not common practice in training or live combat situations to distribute load among soldiers based on %BM. Rather, loads are determined by pre-planned packing lists that meet mission requirements. Consequently, as previously described, the loads which are carried by military personnel can vary widely based on a soldier's role in a squad or platoon and specific mission requirements.

Aside from torso loading, an additional consideration with military populations is footwear mass. When carrying a 30kg backpack, there are significant differences in oxygen uptake not only between a loaded ($1.17 \pm .13$ L$\cdot$ min^{-1}) and unloaded condition ($.85 \pm .06$ L$\cdot$ min^{-1}), but also between standard boots ($1.17 \pm .13$ L$\cdot$ min^{-1}) and weighted boots ($1.57 \pm .12$ L$\cdot$ min^{-1}) while torso loaded (Legg & Mahanty, 1986). Jones, Toner, Daniels, and Knapik (1983) reported an increased oxygen consumption for those wearing boots (15.4, 23.4, 33.6, 38.2, and 42.8 ml$\cdot$kg$^{-1}\cdot$min^{-1}, respectively), compared to those in running shoes (14.2, 21.7, 30.4, 35.2, and 39.6 ml$\cdot$kg$^{-1}\cdot$min^{-1}, respectively), at all speeds (5.6, 7.3, 8.9, 10.5, and 12.1 km$\cdot$h^{-1}, respectively) except for the slowest walking speed (4.0 km$\cdot$h^{-1}). Jones et al. (1983) also tested running shoes compared to running shoes with weights to match boot weight. There was a significant increase in oxygen consumption for the weighted shoe (31.6, 36.0, and 40.2 ml$\cdot$kg$^{-1}\cdot$min^{-1}, respectively) compared to the unweighted running shoes (30.1, 33.9, and 38.2 ml$\cdot$kg$^{-1}\cdot$min^{-1}, respectively) while running (8.9, 10.5, and 12.1 km$\cdot$h^{-1}, respectively) which provides evidence for a primary effect of the weight of the shoes, rather than any difference in biomechanical limitations of boots relative to running shoes. Based on these differences, it is important to conduct future studies using footwear representative of that worn in real-world situations.

Similarly, an additional consideration is the effect of body armor on physiological response during activity. Ricciardi et al. (2008) found that wearing body armor (10 kg) resulted in significantly higher oxygen uptake, heart rate, respiratory exchange ratio (RER), and ventilation values, respectively, at both slow (2.3 mph [women] and 2.4 mph [men]; 16.8 ± 1.5 and 18.8 ± 1.7 $ml \cdot kg^{-1} \cdot min^{-1}$; 107 ± 14.6 and 118 ± 15.5 bpm; 0.87 ± .08 and .89 ± .06; and 25 ± 4.4 and 27.9 ± 4.9 $breaths \cdot min^{-1}$, respectively) and moderate paces (3.6 mph [women] and 3.8 mph [men]; 34.8 ± 3.9 and 40.8 ± 5 $ml \cdot kg^{-1} \cdot min^{-1}$; 164 ± 16.1 and 180 ± 13.3 bpm; .98 ± .1 and 1.1 ± .13; and 34 ± 5.9 and 40.1 ± 6.7 $breaths \cdot min^{-1}$, respectively). These changes in physiological response were not linear as is typically reported when examining load carriage (Borghols et al., 1978; Quesada et al., 2000). Even with similar relative body mass loads (15% BM) as used in other studies, Ricciardi et al. (2008) found that walking while wearing body armor incurred a two to three times higher oxygen uptake despite similar load distribution. The researchers did not investigate the effect of body armor on core temperature, which may cause further alterations in economy. Similarly, these researchers also found that while previous research did not indicate significant changes in RPE with a 15% BM load, the same load mass from body armor caused a significant increase in RPE compared to no body armor (10.4 ± 1.8 and 8.4 ± 1.5, respectively, at slow walking pace and 16.7 ± 2.1 and 14.3 ± 2.3, respectively, at a moderate walking pace). These results are important when considering performance of soldiers during tactical marches, particularly when measuring physiological variables. Soldiers wear the IBA while conducting tactical marches in training and combat. Therefore, including body armor during tactical march performance testing is important, particularly when generalizing results to military performance during training or in austere environments.

An increase in the amount of mass carried has an influence on oxygen uptake, heart rate, RER, and ventilation, and these metabolic responses increase linearly as load increases (Borghols et al., 1978; Quesada et al., 2000; Rose & Gamble, 2006). There are also additional considerations such as footwear and body armor that are important when testing soldier performance. Care should also be taken to simulate real world conditions when evaluating the performance of soldiers under various testing conditions. While researchers agree that the carried mass highly correlates and shows a significant linear relationship with energy expenditure (Borghols et al., 1978; Quesada et al., 2000; Rose & Gamble, 2006), the effects of loading the body may also be dependent on load placement.

Load Placement

There are numerous methods for load carriage during human ambulation. Previous studies have investigated the economy of load carriage at different locations on the human body. Research indicates that the most economical method of load carriage is to carry a load as close to a body's center of mass as possible (Harman, Han, Frykman, & Pandorf, 2000). It has been found that the most economical method of load carriage (i.e., the lowest aerobic demand) occurs when carrying load on the head, as this keeps the load centered on the body's midline (Heglund, Willems, Penta, & Cavagna, 1995). However, some research has indicated that double pack loading (front and back torso load) does not elicit a significantly different energy cost than loading on the head (Datta & Ramanathan, 1971; Lloyd & Cook, 2011). These studies provide evidence for double pack loading to be just as economical, or only marginally less economical, than head loading.

Head loading and double pack loading present some limitations for use during military operations. Particularly in military operations, head loading is impractical as it creates a larger body silhouette, which puts the soldier at greater risk of being targeted by gunfire, and requires extensive training time. Furthermore, particularly in modern urban warfare, it is likely that there would be severe limitations to mobility throughout the urban environment with head loading. Likewise, double pack loading may not be a practical form of load carriage during military operations. Double pack loading may cause limitation of movement, particularly when attempting to maneuver a weapons system, which could decrease mission effectiveness. The double pack can also limit the soldier's field of vision, is difficult to don and doff, and can induce greater ventilatory impairment and heat stress symptoms when compared to back loading (Knapik et al., 2004).

After head and double pack loading, research has indicated back loading as the next most economical form of loading (Datta & Ramanathan, 1971; Knapik et al., 2004). Datta and Ramanathan (1971) found back loading with a rucksack to be significantly less economical than double pack loading, but not significantly different from head loading. Back loading is the most common method of torso loading used within the U.S. Army. Typical back loading for U.S. Army soldiers is generally accomplished by either using a rucksack or an assault pack. Rucksacks are generally larger and used for approach movement while assault packs are smaller, about the size of a standard civilian school backpack, and can be carried during combat missions.

In addition to load placement, load positioning during back loading can also affect performance. Placement of the backpack load higher or lower on the back can change a number of physiological and biomechanical responses. Altering load placement within the pack itself can also induce changes. Even with front and back loading, as commonly seen with assault vests and webbing used to carry small equipment items, moving the load carried from the waist to a higher position on the torso results in a significantly lower oxygen cost, even with relatively light loads (Coombes & Kingwell, 2005).

Previously, Liu (2007) indicated no significant difference in oxygen uptake when backpack load was placed high in the pack compared to low in the pack. Significant increases in respiratory frequency and RER were observed in the high load position compared to the low load position. However, other researchers have found that placement of a load higher in a back pack results in a significantly lower oxygen cost, ventilation rate, and RPE compared to when packed in a central or lower position (Steumpfle, Drury, & Wilson, 2004). These results suggest that placement of heavier items higher in the pack during back loading is the most physiologically economical weight distribution method with an internal frame backpack.

However, when measured as a function of speed, there are significant differences in the energy cost of positioning a load higher or lower on the back. Specifically, Abe, Murake, and Yasukouchi (2008) suggested that a load positioned higher on the back may elicit a significantly lower metabolic demand than a load positioned lower on the back at certain speeds (60 - 80 $m \cdot min^{-1}$). The suggested explanation for these results is that the positioning of load higher on the back results in an increased rotational torque around the center of body mass which contributes to an increase in kinetic energy, saving energy expenditure at speeds between 60-80 $m \cdot min^{-1}$.

Locating the center of mass of the back load as close to the body center of mass as possible results in a lower energy cost (Abe et al., 2008; Steumpfle et al., 2007). Placing a load higher on the back requires less forward trunk lean than a load placed lower on the back, which results in positioning the pack center of mass in line with the body center of mass over the feet (Knapik et al., 2004). Research suggests that high load placement on the human body may be ideal for traversing flat, even terrain, but may promote greater instability on rough terrain, particularly in taller individuals. It is thought that a lower load placement may be ideal for uneven terrain (Knapik et al., 2004).

Overall, load carriage with the load located on the head or front-and-back torso loading appears to be the most economical methods for human transportation of loads. However, these loading approaches are not ideal for military operations. Torso loading with the load placed on the back is the most efficient and practical method of load carriage in military operations. On even, flat terrain, situating the bulk of the load higher in a back-loaded pack may be more ideal as it creates less forward trunk lean to situate the load center of mass closer to the body center of mass over the feet. The location of load on the human torso clearly influences economy of movement. However, there are also changes in gait associated with load carriage which alter the economy of movement.

Spatiotemporal Gait Changes

As discussed previously, in regard to normal human walking, individuals generally self-select a stride length that is not significantly different from the most economical stride length (Morgan & Martin, 1986; Morgan et al., 1989). However, load mass and load position not only affect physiological responses during human ambulation, but can also affect the kinematics and biomechanics of walking and running.

Ghori and Luckwill (1985) found that with loads of 20, 30, 40, and 50% BM, the swing phase of walking gait significantly decreased. However, no significant change was observed with the stance phase. In contrast, Birrell and Haslam (2009) reported a significant increase in the percentage of the gait cycle spent in unilateral stance phase with a concurrent decrease in the percentage of swing time in soldiers and experienced backpackers when back loaded with 8, 16, 24, and 32 kg, respectively. Similarly, Grenier et al. (2012) also observed significant increases in stance duration as load increased in physically active, retired male infantrymen. The difference between changes in stance time found by Birrel and Haslam (2010) and Grenier et al. (2012) may be attributable to the self-selected speeds used by Grenier and colleagues. Attwells, Birrell, Hooper, and Mansfield (2006) similarly found no significant change in stance time. Changes in stance time seem to only occur at fixed paces, not when participants self-select pace as reported by Attwells et al. (2006) and by Ghori and Luckwill (1985). However, it may be important to test military populations at fixed speeds as they are often under time limitations to complete tactical marches in training and austere environments and may not be able to self-select a comfortable walking speed.

The increase in stance time when torso loaded may be related to an increase in double support time (Birrel & Haslam, 2009; Grenier et al., 2012; Harman et al., 2000; Kinoshita, 1985; Ling, Houston, Tsai, Chui, & Kirk, 2004) and a concomitant decrease in single support time (Grenier et al., 2012; Ling et al., 2004). Birrell and Haslam (2009) suggested that an increase in double support time, as consistently seen in the load carriage literature, provides greater control and support during walking by providing a larger base of support for a longer duration and may also decrease internal loads on the joints of the lower limbs. This distinction is an important consideration for the airborne shuffle, as it has been suggested that adopting this mode of gait decreases impact on the knees. Birrell and Haslam (2009) have also stated that the observed increase in double support time occurs as a result of an increase in single leg support which leads to greater overlapping of left and right foot single supports. It is unclear whether this claim is accurate, as Ling et al. (2004) simultaneously observed a decrease in single limb support with an increase in double limb support as load increased.

The aforementioned changes in stance time and swing time with torso loading are accompanied by changes in stride length. With light loads (8 kg), Coombes and Kingswell (2005) detected no significant changes in stride length or frequency in 8 male infantry soldiers torso loaded with different types of assault vests. Birrel and Haslam (2010) also observed a significant main effect of a decrease in stride length with an increase in load carried. Ling et al. (2004) did not find a significant reduction in stride length with increased load carriage in women, however, the authors attributed the lack of statistical significance to their conservative alpha level (.005), insofar as the results did indicate a trend for a reduction in stride length. However, Harman et al. (2000), did not report a significant change in step length with an increase in load carriage. In this study, significant increase in stride frequency was observed between a 47 kg load condition and lighter loads (6, 20, and 33 kg, respectively) which implies a trend towards a decrease in stride length because it is the inverse of stride frequency. Similarly, when measuring step length rather than stride frequency, Kinoshita (1985) did not detect significant changes in stride length with an increase in load carriage. In contrast, Grenier et al. (2012) observed reductions in step length with an increase in load. It is possible that if Harman et al. (2000) had analyzed stride length rather than step length, a significant reduction in stride length may have been observed, as the nonsignificant changes in step length would be amplified when analyzed as stride length. Attwells et al. (2006) also noted the lack of significant change in stride length with an increase in load, but did demonstrate that changes in stride length seem to only occur at fixed paces, and not at self-selected paces that were used in their investigation and the study by Harman et al. (2000).

Decreases in stride length or increases in stride frequency may decrease stress on the metatarsal bones that occur during dorsiflexion of the foot at toe-off during loaded walking (Kinoshita, 1985). Therefore, it would seem that the reasoning for using the airborne shuffle which has been previously reported (Brenes et al., 2015) may have some justification in decreasing lower limb stress during tactical marches. However, while there may be potential benefits to limiting stress placed on the legs while using the airborne shuffle, it is unclear whether the movement technique is more metabolically economical than normal walking. Consequently, further research is needed to determine if the airborne shuffle is a viable movement technique when considering gait characteristics and economy of movement.

Summary of the Literature

In normal human walking, research indicates that changes in stride length from the FCSL can alter the economy of movement as measured using oxygen consumption. Soldiers in the U.S. Army often conduct what are referred to as tactical marches. Tactical marches are conducted in various U.S. Army training schools and in austere environments. During tactical marches, soldiers are often required to physically carry mission essential equipment, usually distributed between a tactical vest and rucksack. Previous research has thoroughly examined the effects of torso loading on the economy of normal walking in soldiers. However, there are a large number of lower limb injuries reported in the military population, possibly due to load carriage while marching.

There is some evidence that a reduction in stride length during load carriage reduces forces on the lower limb during human walking. A technique referred to as the airborne shuffle is sometimes employed to maintain a required speed during a tactical march, while avoiding over-striding. The airborne shuffle is a purposeful manipulation of normal gait which appears to shorten stride length. However, there is a lack of research investigating this specialized mode of gait in the current literature. It is important to understand the gait characteristics of the airborne shuffle as well as the effect it has on economy of movement. If there is significant increase in aerobic demand of ambulation during use of the airborne shuffle, it is possible that any potential benefits associated with a decreased stride length may be outweighed by the increase in aerobic demand.

CHAPTER III

QUANTIFICATION OF GAIT CHARACTERISTICS DURING THE AIRBORNE SHUFFLE IN TORSO LOADED U.S. ARMY SOLDIERS

Introduction

Despite an increasingly technology-driven military force with armored carriers for troop movement in combat, the capability of the individual soldier to travel while loaded with equipment remains paramount to mission success. One of the primary modes of foot travel in the military is the tactical march. This march is a staple of United States Army (U.S. Army) training evaluated in Basic Combat Training (BCT), as well as various other U.S. Army schools, where soldiers are required to complete a given distance in a set time. One consideration when conducting tactical marches is the risk for injury due to heavy loads carried.

Lower-extremity injuries have been reported as one of the most frequently occurring noncombat related musculoskeletal injuries (Kaufman, Brodine, & Shaffer, 2001; Liu, 2007; Ricciardi, Deuster, & Talbot, 2008; Songer & LaPorte, 2000; Warr et al., 2015), particularly among recruits and infantry soldiers (Warr et al., 2015), and may be related to carrying heavy loads during tactical marches (Seay, Fellin, Sauer, Frykman, & Bensel, 2014). Due to the increased potential for lower-extremity injury, running and over-striding are discouraged during tactical marches while torso-loaded (U.S. Department of the Army, 1990). An alternative gait that is employed by soldiers to maintain a given speed of travel, but to avoid running and over-striding, is the airborne shuffle. While gait characteristics of running, walking, and torso-loaded ambulation have been previously investigated (Agostini, Balestra, & Knaflitz, 2014; Attwells, Birrell, Hooper, & Mansfield, 2006; Coombes & Kingswell, 2005; Hamill & Knutzen, 2009; Harman, Han, Frykman, & Pandorf, 2000; Ling, Houston, Tsai, Chui, & Kirk, 2004; Rose & Gamble, 2006), a paucity of data exist on the airborne shuffle.

In a recent paper, Brenes, Caputo, Clark, Wehrly, and Coons (2015) found the airborne shuffle to be less economical than walking at multiple speeds (2.5, 3.0, and 3.5 mph), and speculated that this may be due to a shortened stride length observed in the shuffle. However, little is known regarding the kinematics of the airborne shuffle in either loaded or unloaded conditions and whether this gait pattern more closely resembles a walk or a run. Understanding this alternate mode of foot transport being used by soldiers is important for optimizing soldier performance. Therefore, the purpose of this study was to evaluate and quantify the characteristics of the airborne shuffle by comparing gait characteristics (stride length[SL]; stride frequency [SF]; foot strike [FS]; stance time [ST]; swing time [SW]; single support time [SST]; double support time [DST]; and flight time [FT]) during walking and the airborne shuffle while torso-loaded and unloaded.

Methodology

Participants

A sample of 11 participants, male ($n = 6$) and female ($n = 5$) Army ROTC cadets and Army National Guard soldiers, aged 24.73 ± 3.1 years, were recruited from a university and the community in the southeastern United States. Participants recruited through ROTC were recruited from the MS-III and MS-IV class-levels to ensure a high degree of familiarity and exposure to U.S. Army movement techniques and procedures. Exclusion criteria were the presence of any current musculoskeletal injury or high-risk individuals according to cardiovascular disease risk stratification (American College of Sports Medicine, 2014). All participants were informed of the risks and benefits of participation in the study, both orally and through a written, institutionally-approved informed consent document, prior to beginning the study.

Instrumentation

Health history questionnaire. A health history questionnaire was used to determine if any preexisting health conditions or injuries (especially leg/ankle injuries) were present that may present a danger to the participant and to allow risk classification (American College of Sports Medicine Position Stand, American Heart Association, 1998).

Body mass, height, and heart rate. Body mass was measured using a digital scale (BF-522W, Tanita, Tokyo, Japan), in kilograms, to the nearest 0.1 kg in the Army Physical Fitness Uniform (APFU), without socks or shoes. Mass was also measured with the soldier in full uniform wearing all equipment worn during testing. Height was obtained using a telescopic stadiometer (Seca 222, SECA, Hanover, MD). Height was measured without shoes or socks to the nearest 0.1cm. Heart rate (HR) was measured with a Polar T31 heart rate monitor (Warminster, PA). Heart rate was not recorded for the purposes of this study, only used to determine participant readiness to begin the next trial after a rest period.

Kinematic measurements. The F-scan system (Tekscan Inc., Boston, MA) was used to measure SL, SF, FS, ST, SW, DST, SST, and FT during the last minutes of each trial. Reliability of the F-scan system has been previously investigated and found to be highly reliable in various populations (Ahroni, Boyko, & Forsberg, 1998; Vidmar & Novak, 2009). The F-scan system utilizes an unobtrusive pressure sensing insole with 960 pressure sensing cells embedded in a thin mylar coating. The F-scan system was calibrated for each participant based on total mass while torso loaded and according to manufacturer specifications. Calibration was performed three times or until successful calibration was achieved (Ahroni et al., 1998), for loaded and unloaded conditions. The insoles were trimmed to fit the soldiers' shoe size and inserted into the soldiers' left and right combat boots. Data were recorded wirelessly at 100 Hz via F-scan's VersaTek unit and a dedicated personal computer.

Stance time, SW, DST, SST, and FT were reported in relative terms as a percentage of one full gait cycle measured in seconds. Flight time was measured as the time interval(s) between toe-off and heel contact of the opposite foot. The stance phase of gait can be divided into three periods during walking: initial double limb support, single limb support, and second double limb support (Rose & Gamble, 2006). If a double limb support phase existed in the airborne shuffle condition, stance time was calculated as the total time of initial double limb support, single limb support, and second double limb support until foot-off. However, if the airborne shuffle was similar to a running gait where a double support phase is not present, single limb support time was used. Measurements of stance time and flight time were presented as a percentage of gait cycle.

Treadmill speed. The optimal speed and load during a tactical march is 3.0 mph (1.3 m/s) for a 40.0 lb (18.14 kg) load on easy terrain, according to the Army Field Manual 21-18 (FM 21-18; U.S. Department of the Army, 1990). Typically, the standards set forth by FM 21-18 are used across various Army schools. For example, the 101st Airborne Division has established a Division standard for tactical foot marches of 12 miles in 4 hours, an average speed of 3.0 mph (U.S. Department of the Army, 2011). Participants performed walking and airborne shuffle movements on a calibrated treadmill at 3.0 mph (1.34 m/s) to establish baseline measurements at the minimally-acceptable speed for tactical march evaluation.

Equipment load. The Army has defined standards for equipment loads and movement speeds during tactical marches. Army Field Manual 21-18 (U.S. Department of the Army, 1990) emphasizes that loads are modular and dependent on the tactical situation. The equipment load for this study consisted of a 16.4 lb (7.4 kg) weighted vest, to simulate the Interceptor Body Armor (IBA) with vest and plates only, worn by soldiers in training and austere environments, and a 35.0 lb (15.9 kg) rucksack (M.O.L.L.E.). An advanced combat helmet (ACH; 3.0 lb [1.4 kg]) was worn by participants during all testing. Total equipment load for each participant was 54.4 lb (24.7 kg).

Procedures

This study was approved by the Institutional Review Board at the university. Upon initial arrival at the testing facility, each participant was asked to read and sign an informed consent document. After completion of the informed consent document, each participant then completed the health history questionnaire. Risk classification was performed using the health history questionnaire prior to the participant's next scheduled session. For inclusion in the study, participants also agreed to not consume alcohol 24 hours prior to testing, not consume caffeine or use nicotine 2 hours prior to testing, to maintain proper hydration for 48 hours prior to testing, and to obtain a minimum of 7 hours sleep the night before testing (Brenes et al., 2015). Participants were instructed to arrive for the first laboratory visit in their APFU for measurement of height, body mass, and treadmill familiarization. Participants performed all testing procedures in full Army Combat Uniform (ACU) and combat boots.

All participants were provided the opportunity to familiarize with the treadmill prior to testing. Participants began by walking at 3.0 mph for 5 minutes. After a 5-minute rest period, participants were then instructed to adopt the airborne shuffle gait and performed an additional 5 minutes at 3.0 mph. Following the unloaded familiarization, the participants donned the loaded rucksack, weighted vest, and ACH. The unloaded familiarization procedures were then repeated while torso loaded. Participants were then scheduled for two testing sessions with a minimum of 48 hours of rest between each session.

The order of conditions during testing (walking and shuffle; loaded and unloaded) was semi-randomized for all participants. A randomized unloaded condition preceded a randomized loaded condition during testing. This semi-randomization of test conditions was done to allow the unloaded conditions to act as a warm-up to reduce the risk of strain or injury during the loaded conditions. Walking and shuffling gait conditions, while loaded and unloaded, were performed at 3.0 mph in accordance with minimal acceptable standards for the performance of a 12-mile tactical march time (U.S. Department of the Army, 2011). Each testing condition was 3 minutes. Foot-ground contact data were recorded throughout the duration of the test, however, only the data from the final minute of testing was used in data analysis. Between trials, the participant rested a minimum of 5 minutes, returned to a HR below 120 beats·min^{-1}, and reported being ready to begin the next session (Hardin, van den Bogert, & Hamill, 2004).

Data Analysis

Descriptive statistics were analyzed using IBM Statistical Package for the Social Sciences (SPSS) version 23. A series of two-way repeated measures analysis of variance (ANOVA) *Pillai's F* tests were used to evaluate each of the dependent variables (SL, SR, FS, DST, SST, SW, FT, and ST) across the two gait conditions (airborne shuffle and walk) and the two load conditions (loaded and unloaded) as within-subjects factors. Statistical significance was defined at an alpha of $p < .05$.

Results

Participant characteristics are presented in Table 1. Descriptive statistics for SL, SF, ST, SW, SST, and DST are presented in Table 2. There were statistically significant differences in all temporal gait characteristics. There were significant differences in gait for SL $F(1,10) = 209.82$, p <.001, $\eta_p^2 = .96$, SF $F(1,10) = 125.14$, $p < .001$, $\eta_p^2 = .93$, ST $F(1,10) = 95.24$, $p < .001$, $\eta_p^2 = .91$, SW $F(1,10) = 38.73$, $p < .001$, $\eta_p^2 = .80$, SST $F(1,10) = 187.70$, $p < .001$, $\eta_p^2 = .95$, and DST $F(1,10) = 28.92$, $p < .001$, $\eta_p^2 = .74$. Significant differences were also observed in load for SW $F(1,10) = 8.15$, $p = .02$, $\eta_p^2 = .45$ and DST $F(1,10) = 5.22$, $p = .05$, $\eta_p^2 = .34$.

No significant differences were found in load for SL $F(1,10) = 50.14$, $p = .72$, $\eta_p^2 = .02$, SF $F(1,10) = 1.09$, $p = .32$, $\eta_p^2 = .10$, ST $F(1,10) = 1.70$, $p = .22$, $\eta_p^2 = .15$, and SST $F(1,10) = 1.42$, $p = .26$, $\eta_p^2 = .12$. There were no significant interactions between the gait and load conditions for SL $F(1,10) = 1.67$, $p = .23$, $\eta_p^2 = .14$, SF $F(1,10) = 0.14$, $p = .72$, $\eta_p^2 = .01$, ST $F(1,10) = 0.65$, $p = .44$, $\eta_p^2 = .06$, SW $F(1,10) = 0.23$, $p = .64$, $\eta_p^2 = .02$, SST $F(1,10) = 3.47$, $p = .09$, $\eta_p^2 = .26$, and DST $F(1,10) = 0.89$, $p = .37$, $\eta_p^2 = .08$.

Stride length was longer, stride frequency was lower, and stance time was longer during walking than during the shuffle. Swing time was longer for walking than for the shuffle and longer while unloaded than while loaded. Single support time lasted longer during the walk than during the shuffle. Double support time was longer during walking than during the shuffle and longer while loaded. While FT was recorded, it is not presented in the table because FT did not occur in any of the conditions for any participants, resulting in a value of zero. The lack of FT indicates that the shuffle is more like a walking gait than a running gait.

Table 1

Participant Characteristics

Characteristic	*M*	*SD*
Full sample (*N* = 11)		
Age	24.7	3.1
Body mass	72.8	12.6
Height	167.7	11.2
Females (*n* = 5)		
Age	25.0	2.4
Mass	61.8	6.3
Height	157.6	4.9
Males (*n* = *6*)		
Age	24.5	3.8
Mass	82.0	8.0
Height	176.1	6.7

Note. Age = years of age; Body mass = kg; Height = cm

Table 2

Descriptive Statistics for Gait Characteristics as a Function of Gait and Load Conditions

		Walk		Shuffle	
Gait Characteristic		Unloaded	Loaded	Unloaded	Loaded
Stride length	*M*	1.41	1.40	1.02	1.12
	SD	0.07	0.07	0.10	0.13
Stride frequency	*M*	56.98	57.57	74.40	74.75
	SD	3.15	3.58	7.50	7.76
Stance time	*M*	0.65	0.66	0.47	0.48
	SD	0.03	0.03	0.10	0.07
Swing time	*M*	0.40	0.39	0.35	0.33
	SD	0.03	0.03	0.03	0.03
Single support time	*M*	0.38	0.36	0.30	0.31
	SD	0.03	0.03	0.03	0.03
Double support time	*M*	0.26	0.28	0.16	0.17
	SD	0.03	0.03	0.07	0.07

Note. Stride length = meters; Stride frequency = strides per minute; Stance time, Swing time, Double support time, and Single support time = absolute time in seconds.

Discussion

The purpose of this study was to evaluate and quantify the characteristics of the airborne shuffle by comparing gait characteristics during walking and the shuffle while torso-loaded and unloaded. Overall, the shuffle resembles a walking gait as flight time did not occur during either of the shuffle trials. Additionally, the impacts of torso-loading were similar on walking and the airborne shuffle. However, there are significant differences between the walking gait and the shuffle gait as the modes varied on SL, SF, ST, SWT, SST, and DST.

Measurement of SL and SF are basic methods for characterizing human gait. Stride length was longer and SF was lower during walking than during the shuffle. Similarly, a significantly greater period of time was spent in ST, SWT, SST, and DST while walking than while shuffling. The stance phase during walking typically averages 62% of the gait cycle and is comprised of three periods: initial double limb support, single limb support, and second double limb support. The swing phase of a gait cycle averages 38% of the cycle and is also comprised of three periods: initial swing, mid swing, and terminal swing (Rose & Gamble, 2006). Since the SL was longer during the walking gait, this would lead to an increase in SW and a concurrent increase in ST phases as was seen during the walking gait.

Decreases in stride length or increases in SF may decrease the stress on the metatarsal bones that occur during dorsiflexion of the foot at toe-off during loaded walking (Kinoshita, 1985). Therefore, based on information presented by Brenes et al. (2015) and the results of the current study, using the shuffle as a potential method of reducing lower limb stress during torso loaded tactical marches has some merit. However, the economy of human walking decreases with changes in SL away from freely-chosen stride length (FCSL; Morgan et al., 1994; Morgan, Martin, & Kragenbuhl, 1989; Rose & Gamble, 2006). The alterations in the economy of movement associated with changes in SL may have implications during the airborne shuffle. With a shorter SL, it is possible that the airborne shuffle is significantly less economical than walking, as supported by the research of Brenes et al. (2005) at fixed speeds during torso loaded walking and shuffling. Based on this, there may be a practical application for use of the airborne shuffle in decreasing stress on the lower limbs, but if the shuffle is significantly less economical than walking, it may not be appropriate for use over long distances because having the energy to complete a mission after a tactical march is critical. Alternately, periodic transitions from a walking gait to a shuffle gait during the tactical march may be useful in providing some lower-limb relief from stress while minimizing the impact of the potential lower economy of the shuffle due to changes in gait characteristics.

Since tactical marching almost exclusively occurs when soldiers are torso loaded, understanding the impact of torso loading during the tactical march is important for determining the differences in gait modalities. The decreased swing time while torso loaded in the current sample is similar to changes reported by Ghori and Luckwill (1985) with loads of 20, 30, 40, and 50% BM and Birrel and Haslam (2009) with a decrease in the percentage of SWT in soldiers and experienced backpackers when back loaded with 8, 16, 24, and 32 kg. A decrease in SWT is typically associated with an increase in ST.

However, there were no observed changes in stance time due to the load conditions in the current sample or in the study by Ghori and Luckwill (1985). In contrast, Birrell and Haslam (2009) and Grenier et al. (2012) reported a significant increase in the percentage of the gait cycle spent in the unilateral stance phase with an increase in load at fixed speeds. The differences between changes in ST found by Ghori and Luckwill (1985) may be attributable to participants walking at self-selected speeds as changes in ST with an increase in load typically occur at fixed paces (Attwells et al., 2006). This relationship also did not occur in the current study, even though a fixed speed of 3.0 mph was used for all trials and conditions based on the minimal speed required to pass a 12-mile march (U.S. Department of the Army, 2011). One explanation for why there were no observed differences in ST for the load condition in this study may be the different gait characteristics of the two gait modalities tested. Further, due to the visual analysis of the temporal gait data there may have been errors in interpretation of foot contact times that influenced the results.

An increase in ST when torso loaded is typically related to an increase in DST (Birrel & Haslam, 2009; Grenier et al., 2012; Harman et al., 2000; Kinoshita, 1985; Ling et al., 2004) and a concomitant decrease in SST (Grenier et al., 2012; Ling et al., 2004). This relationship held true in the current study, despite the lack of a change in ST with loading. Birrell and Haslam (2009) suggested that an increase in DST, as consistently seen in the load carriage literature, provides greater control and support during walking by providing a larger base of support for a longer duration. The increased double support time may also decrease internal loads on the joints of the lower limbs. This distinction in

DST is an important characteristic of the airborne shuffle, as it has been suggested that adopting this mode of gait decreases impact on the knees. Birrell and Haslam (2009) have also stated that the observed increase in DST occurs as a result of an increase in single leg support which leads to greater overlapping of left and right foot single supports. It is unclear whether this hypothesis is accurate, as Ling et al. (2004) simultaneously observed a decrease in single limb support with an increase in double limb support as load increased. In contrast to both of these observations, results of the current study did not indicate any change in SST due to the load condition.

There were no differences in SL or SF associated with torso-loading while walking or shuffling. Birrel and Haslam (2009) observed a significant decrease in SL with an increase in load carried. Ling et al. (2004) did not find a significant reduction in SL with increased load carriage in women, however, the authors attributed the lack of statistical significance to the conservative alpha level (.005), insofar as the results did indicate a trend for a reduction in SL. Harman et al. (2000) reported a significant increase in SF between a 47 kg load condition and lighter loads (6, 20, and 33 kg, respectively) which implies a trend towards a decrease in SL because it is the inverse of stride frequency. Attwells et al. (2006) also noted the lack of significant change in SL with an increase in load, but demonstrated that changes in SL occurred only at fixed paces, and not at self-selected paces. Again, this stands in contrast to results of the current study, as testing was done at fixed speeds with no observed change in SL or SF due to loading.

Practical Applications

In conclusion, while the shuffle is a walking gait without FT, the shuffle has a shorter SL, greater SF, shorter ST, shorter SWT, shorter SST, and shorter DST than a walking gait. As a shorter SL can decrease stress on the metatarsals, there is some justification for the use of the shuffle as a method of reducing lower limb stress during torso loaded tactical marches. However, previous research has shown the shuffle to be less economical at various speeds when compared to walking under torso load. It is not clear at this time whether the shuffle should be used during torso loaded tactical marches over the walk. Maintaining an optimal aerobic demand during tactical marches is critical for ensuring soldiers can endure the entirety of the march over extended distances and still have the energy to complete a mission upon arrival at a destination. While there are potential benefits with lower limb stress reduction and the reduction of incidence of lower limb injury in service members, it is possible that the economy differences between walking and shuffling may negate any potential benefits of the shuffle. Further research is needed at absolute and relative speeds, absolute and relative loads, and with additional equipment configurations such as carrying a weapon, to fully understand economy differences between a standard walking gait and a shuffle during torso loaded tactical marches.

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APPENDIX FOR STUDY I

APPENDIX A

IRB Approval Letter

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Tuesday, November 29, 2016

Investigator(s): Casey Clark (PI), and Dr. Jennifer Caputo (FA)
Investigator(s') Email(s): CBC4v@mtmail.mtsu.edu
Department: Exercise Science

Study Title: THE TACTICAL MARCH: QUANTIFICATION OF THE GAIT AND ECONOMY OF THEAIRBORNE SHUFFLE IN TORSO LOADED U.S. ARMY CADETS
Protocol ID: **17-2034**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(4) Collection of data through noninvasive procedures* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	APPROVED for one year from the date of this notification	
Date of expiration	10/31/2017	
Participant Size	50	
Participant Pool	18+ male MTSU ROTC MS-III and MS-IV cadets	
Exceptions	N/A	
Restrictions	**Musculoskeletal injury or high-risk individuals according to cardiovascular disease risk stratification. Females will also be excluded due to a small # of available females in the ROTC program**	
Comments	N/A	
Amendments	**Date**	**Post-approval Amendments**
	11/29/2016	1. Eric Scudamore is added as an investigator. 2. Revision of recruitment selection statement.

This protocol can be continued for up to THREE years (10/31/2019) by obtaining a continuation approval prior to 10/31/2017. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Continuing Review Schedule:

Reporting Period	Requisition Deadline	IRB Comments

First year report	10/31/2017	INCOMPLETE
Second year report	10/31/2018	INCOMPLETE
Final report	10/31/2019	INCOMPLETE

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

Click here for a detailed list of the post-approval responsibilities.
More information on expedited procedures can be found here.

CHAPTER IV

PREFERRED WALKING SPEED AND PREFERRED SHUFFLE SPEED IN TORSO LOADED U.S. ARMY SOLDIERS

Introduction

The military's ability to move troops and equipment is a critical aspect of mission success. Although the nature of tactical movement has changed with the advent of armored troop carriers and other advances in military technology, the ability of the individual soldier to physically move from location to location under equipment load remains an important military tactic. As such, the ability of soldiers to complete tactical marches in set times is evaluated in many United States Army (U.S. Army) schools including Basic Combat Training (BCT) and Air Assault and Airborne school.

While marches must be completed within a minimum time to pass, running and over-striding are not recommended due to the potential for lower-extremity injury while torso loaded (U.S. Department of the Army, 1990). The airborne shuffle is an alternative gait pattern used by soldiers during marches that is purported to reduce strain on the lower limbs while allowing distance to be covered at a faster pace. However, it is important for mission success that the mode of ambulation selected conserve energy and currently, there are limited data on the economy of the airborne shuffle while torso loaded. In one investigation, the airborne shuffle was found to be less economical than walking under torso load at set speeds of 2.5, 3.0, and 3.5 mph (Brenes, Caputo, Clark, Wehrly, & Coons, 2015). The lower economy may be due to a reduction in stride length observed during the airborne shuffle (Brenes et al., 2015). However, there may also be a preferred speed at which the airborne shuffle is used by soldiers where economy values do not differ significantly from walking.

The 'preferred' walking speed (PWS) in adults, sometimes referred to as freely-chosen walking speed, tends to be a speed at or near the most economical speed (Chung & Wang, 2010; Corcoran & Brengelmann, 1970; Dal, Erdogan, Resitoglu, & Beydagi, 2010; Morgan & Martin, 1986; Morgan, Martin, & Krahenbuhl, 1989; Ralston, 1958; Rose & Gamble, 2006). Currently, there is no literature on the preferred shuffle speed (PSS) in male U.S. Army soldiers nor data on how economy values may differ between walking and shuffling under load at a soldier's preferred speeds. Therefore, the purpose of this study was first to determine the PWS and the PSS in Army service members under torso load. The second purpose was to compare the oxygen demand (VO_2), heart rate (HR), respiratory exchange ratio (RER), ventilation (Ve), and rating of perceived exertion (RPE) of the PWS and the PSS under torso load. It was hypothesized that the speed, VO2 in ml/kg/min, HR, RER, Ve, and RPE of the PWS and the PSS would be different.

Methodology

Participants

Male ($n = 5$) and female ($n = 4$) Reserve Officer Training Corps (ROTC) cadets and Army National Guard soldiers, aged 24 ± 2 years, were recruited from a university and community in the southeastern United States. Cadets were recruited from the junior and senior class-levels of an ROTC command. The recruitment of cadets from these classes was done to ensure familiarity with the movement techniques and procedures used by the U.S. Army. Any individual with current lower limb injury or high-risk individuals according to cardiovascular disease risk classification (American College of Sports Medicine, 2014), were excluded from participation in the study. Participants were informed of the risks and the benefits of the study through an institutionally approved informed consent document.

Instrumentation

Health history questionnaire. A health history questionnaire was used to determine if any preexisting health conditions or injuries (especially leg/ankle injuries) were present that may present a danger to the participant and to allow risk classification (American College of Sports Medicine Position Stand, American Heart Association, 1998).

Body mass and height. Body mass was measured using a digital scale (BF-522W, Tanita, Tokyo, Japan) in kilograms to the nearest 0.1 kg in the Army Physical Fitness Uniform (APFU) without socks or shoes. Participants were then weighed while torso loaded and wearing the Army Combat Uniform (ACU) to determine total mass (TM). Height was obtained using a telescopic stadiometer (Seca 222, SECA, Hanover, MD) without shoes or socks to the nearest 0.1cm.

Equipment load. The U.S. Army has defined standards for equipment loads and movement speeds during tactical marches. The Army Field Manual (FM) 21-18 (U.S. Department of the Army, 1990) emphasizes that loads are modular and dependent on the tactical situation, but fighting loads should not exceed 48.0 lb (21.8 kg) and approach loads should not exceed 72.0 lb (32.7 kg). The torso load for this study consisted of a 16.4 lb (7.4 kg) weighted vest, to simulate the Interceptor Body Armor (IBA; vest and plates only) worn by soldiers in tactical situations, a 35.0 lb (15.9 kg) rucksack packed with clothing (MOLLE II), and a 3.0 lb (1.4 kg) advanced combat helmet (ACH). Total equipment load for each participant was 54.4 lb (23.3 kg), which falls under the maximum suggested load for approach marches. Weight distribution within the pack was situated with the heaviest weight toward the top of the pack, which has been found to be an optimal packing configuration on easy terrain (Abe, Murake, & Yasukouchi, 2008; Knapik, Reynolds, & Harman, 2004; Steumpfle, Drury, & Wilson, 2004). Participants performed all testing procedures in the full ACU and combat boots.

VO_2, RER, V_e, HR, and RPE. Open-circuit spirometry using an AEI Moxus metabolic cart (Naperville, IL) and V2 mask (Hans Rudolph, Inc., Shawnee, KS) was used to measure VO_2, RER, and V_e. Equipment calibration was performed daily using room air (0.03% CO_2, 20.93% O_2) and a certified gas mixture (4.00% CO_2, 16.08% O_2) according to manufacturer specifications. A 3,000 mL calibration syringe was used to calibrate the metabolic cart flow and volume according to manufacturer specifications. Heart rate was measured with a Polar T31 heart rate monitor (Warminster, PA). Rating of perceived exertion was recorded on a scale of 1-10 at the end of the 5th and 6th minutes of testing by holding the scale in front of the participant and having him or her indicate RPE by holding up the number on his or her fingers. The last 2 minutes of data for each trial were averaged to determine VO_2, RER, Ve, HR, and RPE for each condition.

Procedures

Before data collection, this study was approved by the Institutional Review Board at the University (see Appendix A). Upon arrival at the testing facility, each participant was asked to read and sign an informed consent document. Review and signing of the informed consent document was observed by the researcher with full disclosure of the testing procedures and expectations. Risks and benefits were also verbally explained and any questions answered. A health history questionnaire (American College of Sports Medicine Position Stand, American Heart Association, 1998) was used to classify each participant based on ACSM guidelines (American College of Sports Medicine, 2014) and to assure that no participant was high risk. For inclusion in the study, participants also agreed to not consume alcohol 24 hours prior to testing, not consume caffeine or use nicotine 2 hours prior to testing, to maintain proper hydration for 48 hours prior to testing, and to obtain a minimum of 7 hours sleep the night before testing (Brenes et al., 2015).

Participants were instructed to attend the first meeting in the APFU. Body mass, TM, and height measurements were assessed prior to familiarization to the treadmill and the testing equipment. Participants donned the loaded rucksack, weighted vest, ACH, HR monitor, and V2 mask and stood on the treadmill for 5 minutes to obtain a baseline measure of VO_2 while standing stationary torso loaded. Following the baseline measurement, the participants walked at 3.0 mph on the treadmill for 5 minutes. After a 5 minute rest period, participants adopted the airborne shuffle gait and performed an additional 5 minutes at 3.0 mph. Participants were then scheduled for two testing sessions with a minimum of 48 hours of rest between sessions.

Preferred walking and shuffle speeds. While determining the PWS and PSS, the speed of the treadmill was blinded to participants. The order of the PWS and PSS trials was randomized across participants. To determine PWS, the participants began walking while torso loaded at a speed of 0.5 mph. Speed was increased by the researcher in 0.1 mph increments until the participant reported the current speed as faster than preferred. The current speed was then recorded as the faster speed. Treadmill speed was then increased by 1.0 mph from the current speed, followed by a decrease of speed in 0.1 mph increments until the participants reported that the speed was slower than preferred. The current speed was recorded as the slower speed (Chung & Wang, 2010; Dal et al., 2010). This procedure was repeated three times and PWS was determined as the average of the three slower and three faster speeds. Between trials, the participants rested a minimum of 5 minutes, until their HRs returned to below 120 beats$\cdot$min^{-1}, and they reported being ready to begin the next session (Hardin, van den Bogert, & Hamill, 2004). The PSS was determined in the same manner as the PWS while the participants shuffled.

On the third visit, participants performed 6 minute bouts of walking and the airborne shuffle at the PWS or PSS, respectively, while torso loaded, to determine VO_2, RER, Ve, HR, and RPE for the respective condition. The data from the last 2 minutes of each condition were averaged for each variable. The order of conditions was randomized. Following the first condition, the participant rested according to the previously used procedure before completing the remaining condition.

Data Analysis

All data were analyzed using IBM Statistical Package for the Social Sciences (SPSS) version 23. A series of paired samples t-tests were used to test for differences in speed, VO_2, RER, Ve, HR, and RPE at the PWS and the PSS. Significance was determined at an alpha level of $p < .05$.

Results

Participant characteristics are presented in Table 1 for the full sample. All variables were significantly different between the PWS and the PSS (see Table 2). The paired samples t-tests indicated that preferred speed, VO_2, HR, RER, Ve, and RPE were all higher during the shuffle than during the walking gait.

Discussion

A primary focus in the load carriage literature is the metabolic demand of carrying a given load, as oxygen consumption is linked to time to exhaustion during load carriage tasks. In recognition of this, the gait conditions in this study were performed with torso loading to allow generalization of the results to soldiers performing a tactical march. The hypothesis that treadmill speed, VO_2, HR, RER, V_e, and RPE of the preferred walking speed and the preferred shuffle speed would be different was supported.

In the current sample, the preferred shuffle speed was faster (14.3%, 0.5mph) than the preferred walking speed. The faster shuffle speed likely explains the higher VO_2 (42.4%, 6.77 ml/kg/min), HR (13.8%, 20 bpm), RER (10.5%, or 0.1), V_e (48.7%, 21.97 L/min), and RPE (80%, 1.6). Any increase in the intensity of physical activity, such as an increase in speed, will increase the aerobic demand of ambulation. However, the economy of human walking also decreases with changes in stride length away from FCSL (Morgan et al., 1994; Morgan et al., 1989; Rose & Gamble, 2006).

An individual's naturally occurring stride length at a given speed is typically not significantly different from the most economical stride length in race walking and running (Morgan et al., 1994; Morgan & Martin, 1986; Morgan et al., 1989). With deviations above or below FCSL, the aerobic demand of walking increases in a curvilinear fashion (Morgan et al., 1994; Morgan et al., 1989), with a greater increase in oxygen consumption when stride length is increased beyond FCSL (Morgan et al., 1994).

The alterations in the economy of movement associated with changes in stride length may have implications during the airborne shuffle, as the shuffle is a purposeful manipulation of gait away from a natural walking gait, but not into a running gait. With a shorter stride length, the airborne shuffle, while torso-loaded, has been observed to be significantly less economical than walking while torso-loaded at speeds of 2.5, 3.0, and 3.5 mph (Brenes et al., 2015). Similarly, our data indicate that even at a self-selected, preferred speed, the shuffle was less economical than walking. The differences in gait between walking and shuffling were also likely a factor in the higher HR, RER, and V_e during the shuffle, as these physiological measures typically show a linear relationship with VO_2. Similarly, the greater perception of effort, as reflected by the higher RPE during the shuffle, was likely due to both the difference in the absolute intensity of the faster speed as well as the purposeful manipulation of the gait during the shuffle away from a normal walking gait. Therefore, the shuffle is not only less economical than walking, but is perceived as more difficult.

Table 1

Participant Characteristics

Characteristic	*M*	*SD*
Full sample (*N* = 9)		
Age	24	2
Body mass	71.88	12.66
Height	169.20	10.91
Females (*n* = 4)		
Age	25	2
Body mass	60.88	6.81
Height	159.20	3.81
Males (*n* = 5)		
Age	23	1
Body mass	80.68	8.22
Height	177.20	6.86

Note. Age = years of age; Body mass = kg; Height = cm.

Table 2

Differences Between the Preferred Walking Speed and the Preferred Shuffle Speed

	PWS		PSS					
Measure	*M*	*SD*	*M*	*SD*	*df*	*t*	*p*	Cohen's *d*
Preferred speed	3.5	0.6	4.0	0.5	8	-2.54	*0.035	0.85
VO_2	15.96	3.59	22.73	4.41	8	-4.35	*0.002	1.45
HR	145	18	165	16	8	-3.21	*0.002	1.07
RER	0.95	0.09	1.05	0.08	8	-4.76	*0.001	1.59
V_e	45.14	8.51	67.11	13.38	8	-4.62	*0.002	1.54
RPE	2	1	4	2	8	-4.47	*0.002	1.49

Note. * = significance at the .05 level; Speed = mph; PWS = preferred walking speed; PSS = preferred shuffle speed; VO_2 = ml/kg total mass/min; HR = heart rate in bpm; RPE = rating of perceived exertion on a scale of 0-10; RER = respiratory exchange ratio; V_e = ventilation in L/min.

Practical Applications

It has been reported that one of the reasons the airborne shuffle is used in the Army is that it is a method of decreasing lower limb stress during torso-loaded tactical marches (Brenes et al., 2015). Reduction of the incidence of lower limb injury is a significant concern as lower-extremity injuries are some of the most frequently occurring noncombat related musculoskeletal injuries (Kaufman Hughes, Morrey, & An, 2001; Liu, 2007; Ricciardi, Deuster, & Talbot, 2008; Songer & LaPorte, 2000; Warr et al., 2015), particularly among recruits and infantry soldiers (Warr et al., 2015). However, potential reductions in the rate of injury must be weighed against alterations in economy of movement. Our findings indicate that the shuffle (at a self-selected, preferred speed) is a less economical method of movement than normal walking. Therefore, while it is possible that the shuffle may reduce stress on the lower limbs due to its shorter stride length, it cannot be recommended for use over walking during tactical marches due to the higher metabolic cost and perception of effort.

CHAPTER IV REFERENCES

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APPENDIX FOR STUDY II

APPENDIX A

IRB Approval Letter

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Tuesday, November 29, 2016

Investigator(s): Casey Clark (PI), and Dr. Jennifer Caputo (FA)
Investigator(s') Email(s): CBC4v@mtmail.mtsu.edu
Department: Exercise Science

Study Title: THE TACTICAL MARCH: QUANTIFICATION OF THE GAIT AND ECONOMY OF THEAIRBORNE SHUFFLE IN TORSO LOADED U.S. ARMY CADETS
Protocol ID: **17-2034**

Dear Investigator(s),

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Exceptions	N/A	
Restrictions	**Musculoskeletal injury or high-risk individuals according to cardiovascular disease risk stratification. Females will also be excluded due to a small # of available females in the ROTC program**	
Comments	N/A	
Amendments	**Date**	**Post-approval Amendments**
	11/29/2016	1. Eric Scudamore is added as an investigator. 2. Revision of recruitment selection statement.

This protocol can be continued for up to THREE years (10/31/2019) by obtaining a continuation approval prior to 10/31/2017. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

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Reporting Period	Requisition Deadline	IRB Comments

First year report	10/31/2017	INCOMPLETE
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The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

Click here for a detailed list of the post-approval responsibilities.
More information on expedited procedures can be found here.

CHAPTER V

MOST ECONOMICAL SHUFFLE SPEED AND PREFERRED SHUFFLE SPEED IN TORSO LOADED U.S. ARMY SOLDIERS

Introduction

Torso loaded tactical marches are often performed during United States Army (U.S. Army) training schools such as basic combat training (BCT), Air Assault, and Reserve Officer Training Corps (ROTC) programs (U.S. Department of the Army, 2011). These tactical marches are used as an evaluation tool because U.S. Army soldiers are often required to carry heavy equipment and supply loads in modern combat environments. While there can be different standards for completion among U.S. Army training schools, performance in all schools is evaluated on completion time.

The airborne shuffle is an altered gait pattern sometimes used by soldiers to maintain speed during marches to avoid over striding and running. While completion time is a key evaluation tool, it is also necessary for mission success that soldiers conserve energy in order to be able to complete mission objectives at the end of the march. The shuffle has been compared to walking at different speeds (2.5, 3.0, and 3.5 mph) and found to be less economical under torso load (Brenes, Caputo, Clark, Wehrly, & Coons, 2015). However, it is unclear whether these speeds represent the most economical speeds for torso loaded walking and shuffling.

A freely chosen or preferred walking speed (PWS) in adults tends to be at or near the most economical or optimal walking speed (OWS; Chung & Wang, 2010; Corcoran

& Brengelmann, 1970; Dal, Erdogan, Resitoglu, & Beydagi, 2010; Ralston, 1958; Rose & Gamble, 2006). However, there is a lack of information on whether the preferred shuffle speed (PSS) is at or near the most economical shuffle speed (ESS) in U.S. Army soldiers while torso loaded. Therefore, the purpose of this study was to determine the ESS, compare the speed at the ESS to the speed at the PSS, and then examine differences in oxygen demand (VO_2), respiratory exchange ratio (RER), ventilation (Ve), heart rate (HR), and rating of perceived exertion (RPE) during the airborne shuffle at the PSS and the ESS while torso loaded. It was hypothesized that all dependent variables would be significantly different between the PSS and the ESS.

Methodology

Participants

Male (*n = 5)* and female (*n= 3)* Reserve Officer Training Corps (ROTC) cadets and Army National Guard soldiers were recruited from a university and the community in the southeastern United States. Cadets were recruited from the MS-III and MS-IV class-levels to ensure familiarity and exposure to U.S. Army movement techniques and procedures. The presence of any current lower limb injury, high risk individuals according to American College of Sports Medicine cardiovascular disease risk classification (American College of Sports Medicine, 2014), and age not between 18-30 years were exclusion criteria. All participants were informed of the risks and benefits of participation in the study through an institutionally-approved, written informed consent document.

Instrumentation

Health history questionnaire. A health history questionnaire was used to determine if any preexisting health conditions or injuries (especially leg/ankle injuries) were present that may have presented a danger to the participant and to allow risk classification (American College of Sports Medicine Position Stand, American Heart Association, 1998).

Body mass and height. Body mass was measured using a digital scale (BF-522W, Tanita, Tokyo, Japan) in kilograms to the nearest 0.1 kg in the Army Physical Fitness Uniform (APFU) without socks and shoes. Body mass was recorded a second time while torso loaded to determine total mass (TM). Height measurements were obtained using a telescopic stadiometer (Seca 222, SECA, Hanover, MD) without shoes or socks to the nearest 0.1cm.

Equipment load. Although soldier carried loads are modular and based on the tactical situation, fighting loads should not exceed 48.0 lbs (21.8 kg) and approach loads should not exceed 72.0 lbs (32.7 kg; U.S. Department of the Army, 1990). The equipment loads for this study consisted of a 16.4 lbs (7.4 kg) weighted vest, to simulate the Interceptor Body Armor (IBA) with vest and plates only, a 35.0 lb (15.9 kg) rucksack (M.O.L.L.E.), and an advanced combat helmet (ACH; 3.0 lbs [1.4 kg]). Total equipment load for each participant was 54.4 lbs (24.7 kg). The rucksack used for torso loading was packed by the researcher. Clothing was used to pack the rucksack to the desired mass of 35.0 lbs (15.9 kg). Pack load was distributed with the heaviest portion of the weight toward the top of the pack according to previous research which has shown this is an optimal packing configuration for easy terrain (Abe, Murake, & Yasukouchi, 2008; Knapik, Reynolds, & Harman, 2004; Steumpfle, Drury, & Wilson, 2004). All testing procedures were performed in full ACU and combat boots.

VO_2, RER, Ve, HR, and RPE. Oxygen demand, RER, and V_e were measured with open-circuit spirometry using an AEI Moxus metabolic cart (Naperville, IL). The system was calibrated using room air (0.03% CO_2, 20.93% O_2) and a known concentration gas (4.00% CO_2, 16.08% O_2). Flow and volume were calibrated via a 3,000 mL syringe according to manufacturer instructions. Gas samples were collected through a facemask (V2 mask, Hans Rudolph Inc., Shawnee, KS) and 2,700 series 2-way rebreathing valve. Heart rate was measured using a Polar T31 HR monitor (Warminster, PA). A 0-10 scale was used to determine RPE with 0 being no effort and 10 being maximal effort. Oxygen demand, RER, Ve, HR, and RPE data averaged over the last 2 minutes of each trial were used for analyses.

Procedures

Before data collection, this study was approved by the Institutional Review Board at the University (see Appendix A). Participants were instructed to attend the first meeting in their APFU. Upon arrival at the testing facility, each participant was asked to read and sign the informed consent document. Review and signing of the document was observed by the researcher with full disclosure of the testing procedures, expectations, risks, and benefits also being verbally explained and any questions answered. The health history questionnaire was completed and used to determine if any preexisting health conditions or injuries were present that may present a danger to the participant and to conduct the cardiovascular risk classification. For inclusion in the study, participants also agreed to not consume alcohol 24 hours prior to testing, not consume caffeine or use nicotine 2 hours prior to testing, to maintain proper hydration for 48 hours prior to testing, and to obtain a minimum of 7 hours sleep the night before testing (Brenes et al., 2015).

Body mass, TM, and height measurements were recorded during the first laboratory visit. After donning all test equipment, participants stood stationary on the treadmill for 5 minutes to obtain a baseline measure of VO_2 while torso loaded. Test familiarization was then conducted to ensure all participants were familiar with the treadmill and loads to be utilized during testing. During familiarization, participants performed the airborne shuffle on the treadmill for 5 minutes at 4.8 kmh. Participants were then scheduled for three testing sessions with a minimum of 48 hours of rest between sessions. Each participant was tested at the same time of day for each session. The second and third laboratory visits were used for the determination of the PSS and the economy of the PSS. The fourth visit was used to determine the ESS.

Preferred shuffle speed and most economical shuffle speed. The speed of treadmill movement was blinded for all participants while performing the airborne shuffle on the treadmill. Participants began shuffling on the treadmill while torso loaded at a speed of 0.8 kmh. Speed was increased by the researcher in 0.16 kmh increments, for 10 seconds at each speed, until the participant reported the current speed as faster than preferred. The current speed was then recorded as the faster speed. Treadmill speed was then increased 3.9 kmh from the current speed, followed by a decrease of speed in 0.16

mph increments until the participant reported that the speed was slower than preferred. The current speed was then recorded as the slower speed (Chung & Wang, 2010; Dal et al., 2010). This procedure was repeated three times. The PSS was determined as the average of the three slower and three faster speeds. Participant were then given 5 minutes of rest before continuation of data collection. Following the rest period, participants performed the airborne shuffle at the PSS for 6 minutes while O_2 cost, HR, and RER were measured and the last 2 minutes of each variable averaged for data analysis (Brenes et al., 2015).

To determine the ESS, participants performed the airborne shuffle at speeds 5%, 10%, and 15% above and below the PSS. The order of speeds during ESS testing was randomized. The participants performed the airborne shuffle at each speed for 6 minutes. Between trials, there was a minimum of 5 minutes rest, HR returned below 120 beats$\cdot$min^{-1}, and the participants reported being ready to begin the next session (Hardin, van den Bogert, & Hamill, 2004). The final 2 minutes of VO_2 were averaged for each trial. Average VO_2 for each speed was plotted against speed to create an oxygen uptake curve for determination of ESS. The study was originally designed to determine the ESS as the lowest point on the oxygen uptake curve. However, this method was not possible so the ESS was determined as the actual speed where the lowest VO_2 was recorded for each participant.

Data Analysis

Descriptive statistics were analyzed using IBM Statistical Package for the Social Sciences (SPSS) version 23. A graphical estimation of the most economical shuffle speed was not possible due to the economy curves deviating from the typical U-shaped curve seen during walking and running gaits. Because the economy curves were not approximately U-shaped, established methods of ESS estimation could not be used as they are based on a quadratic regression (Horiuchi, Endo, Horiuchi, & Abe, 2015). Additionally, a cubic relationship could not be determined due to collinearity of the data. Because estimation was not possible through quadratic or cubic regression, the lowest measured VO_2 for each participant at either the -15%, -10%, -5%, at PSS, 5%, 10%, 15% was recorded as the most ESS. Paired samples t-tests were used to test for differences at the corresponding speed, VO_2, HR, RER, V_e, and RPE for each participant's ESS. An alpha of .05 was used.

Results

Participant characteristics ($N = 8$) are presented in Table 1. Figure 1 contains oxygen economy curves for speeds at 5%, 10%, and 15% above and below PSS for each participant. The average speed, VO_2, HR, RER, V_e, and RPE at the PSS and ESS are presented in Table 2. There was a significant difference in VO_2 between the PSS and the ESS (see Table 2). There were no differences detected for speed, HR, RER, V_e, or RPE between the PSS and the ESS (see Table 2).

Table 1

Participant Characteristics

Characteristic	*M*	*SD*
Full sample ($N = 8$)		
Age	24	2
Body mass	73.3	12.8
Height	170.7	10.7
Females ($n = 3$)		
Age	24	2
Body mass	60.9	8.3
Height	159.8	4.5
Males ($n = 5$)		
Age	23	1
Body mass	80.7	8.2
Height	177.2	6.9

Note. Age = years; Body mass = kg; Height = cm.

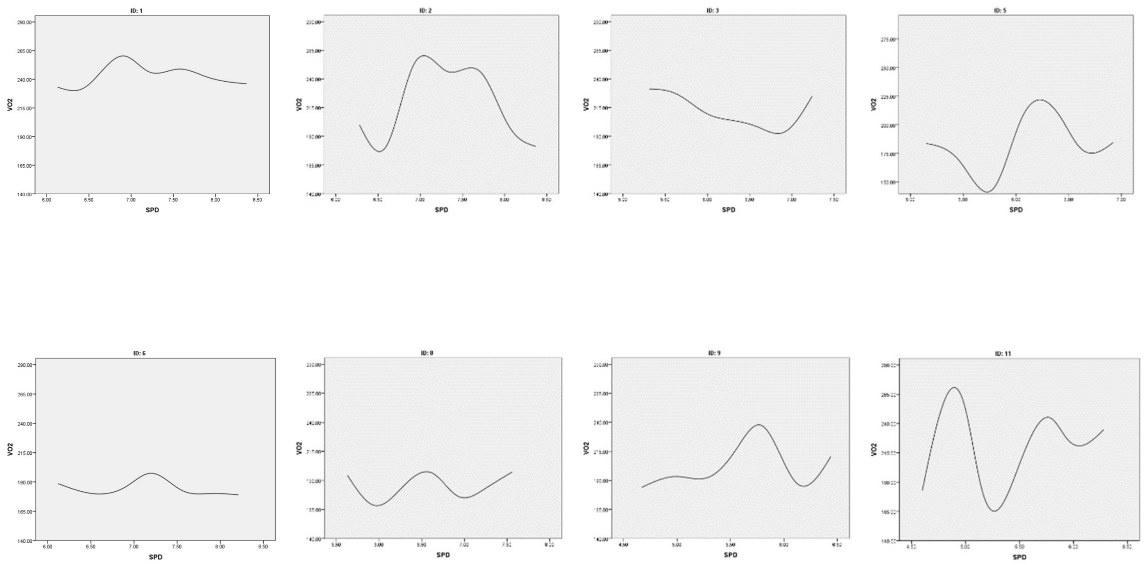

Figure 1. Oxygen economy curves for speeds at 5%, 10%, and 15% above and below preferred shuffle speed for each participant. Oxygen economy is in ml/kg/km on the y-axis and speed is in kmh on the x-axis.

Table 2

Differences Between the Preferred Shuffle Speed and the Most Economical Shuffle Speed

	PSS		ESS					
Measure	*M*	*SD*	*M*	*SD*	*df*	*t*	*p*	Cohen's *d*
Speed	6.5	0.7	6.2	1.2	7	1.19	0.27	0.42
VO_2	213.72	21.25	183.29	21.25	7	4.07	*0.005	1.44
HR	163	17	161	25	6	0.17	0.53	0.25
RER	1.05	0.09	1.04	0.10	7	0.66	0.87	0.06
V_e	67.47	14.26	63.13	22.27	7	0.76	0.46	0.27
RPE	4	2	3	2	7	0.98	0.36	0.34

Note. * = Significance at the .05 level; Speed = kmh; VO_2 = Oxygen consumption in ml/kg total mass/km; HR = Heart rate in beats per minute; RER = Respiratory exchange ratio; V_e = Ventilation in L/min; RPE = Rating of perceived exertion on a 0-10 scale.

Discussion

In the Army, soldiers cover ground while torso loaded using the airborne shuffle, which is a purposeful manipulation of the walking gait characterized by a shortened stride length. In addition to the need to be able to complete tactical marches, soldiers must also be able to optimally perform mission requirements upon arrival at a destination. Ideally, the mode of locomotion maximizes speed while minimizing energy expenditure. This study was designed to test differences between the PSS and the ESS. The hypothesis that speed, HR, RER, V_e, and RPE would be significantly different between the shuffle at the PSS and at the ESS was not supported. However, VO_2 was different between the PSS and the ESS.

An individual's naturally occurring stride length at a given speed is typically not significantly different from the most economical stride length in race walking and running (Morgan et al., 1994; Morgan & Martin, 1986; Morgan, Martin, & Krahenbuhl, 1989). With deviations above or below the FCSL, the aerobic demand of walking increases in a curvilinear fashion (Morgan et al., 1994; Morgan et al., 1989), with a greater increase in oxygen consumption when stride length is increased beyond FCSL (Morgan et al., 1994). The VO_2 at the PSS (213.72 ± 21.25 ml/kg/km; 23.12 ± 2.30 ml/kg/min) was higher than the VO_2 at the ESS (183.29 ± 21.25 ml/kg/km; 18.94 ± 2.20 ml/kg/min). However, speed (6.5 ± 0.7 kmh and 6.2 ± 1.2 kmh), HR (163 ± 17 bpm and 161 ± 25 bpm), RER (1.05 ± 0.09 and 1.04 ± 0.10), Ve (67.46 ± 14.26 L/min and 63.13 ± 22.27 L/min), and RPE (4 ± 2 and 3 ± 2) were not different between the PSS and the ESS, respectively.

While not statistically different, speed was 0.3 kmh (4.9%) faster at the PSS (6.5 ± 0.7 kmh) than at the ESS (6.2 ± 1.2 kmh). It is possible that the raw difference in the speeds impacted the gait of the shuffle and altered the economy of movement. Correspondingly, the approximate 5% difference in speed may have led to an altered stride length to cause a change in VO_2 and altering the economy of movement.

The lack of differences in HR, RER, Ve, and RPE suggests there may have be an error in the VO_2 measurements. The participant VO_2 curves presented in Figure 1, while consistent with other loaded marching ranges at 6 kmh with 30%-70% body mass (155 ml/kg/km – 466 ml/kg/km; Beekley, Alt, Buckley, Duffey, & Crowder, 2007), were inconsistent and atypical with what is usually seen with increases in speed. However, with increases in speed by 0.8 kmh increments during a loaded shuffle, Brenes et al. (2015) reported an increase in VO_2 of 1.96 ml/kg/min from 4.0 kmh to 4.8 kmh and 2.54 ml/kg/min from 4.8 kmh to 5.6 kmh. In the current study, similar changes were found when VO_2 was examined in ml/kg/min instead of ml/kg/km with an average increase in VO_2 of 4.76 ml/kg/min from 85% PSS to 100% PSS (0.8 kmh). Based on these similarities, it seems unlikely there was measurement error for VO_2. However, since this is the first study examining shuffle VO_2 relative to distance travelled, it is unclear if the VO_2 values and uptake curves are representative of the shuffle. Another consideration may be the torso load relative to the body mass of the participants. On average, the participants were heavier in the study by Brenes et al. (2015), which would explain a lower VO_2 difference compared to the current study with a 0.8 kph change in speed. This is likely attributable to the inclusion of both males and females in the current study, whereas Brenes et al. included only male participants.

Typically, with physical activity, when there is an increase in intensity, such as an increase in speed, there is a linear relationship between the increase in O_2 demand and HR (Waters, Lunsford, Perry, & Byrd, 1988). Similarly, as VO_2 increases so do measurements of RER and V_e. Rating of perceived exertion also typically rises with an increase in intensity. While load mass was controlled in this study, the load was an absolute mass and not relative to body mass. This was done to accurately represent real-world situations where soldier load mass is absolute based on packing lists rather than based on the body mass of the soldier. However, with an increase in percent body mass carried during road marching, there are significant increases in HR, $\%VO_{2max}$, RER, V_e, and RPE (Beekley et al., 2007; Ricciardi, Deuster, & Talbot, 2008). It is possible that the current data may be obscured by differences in physiological response to the absolute mass carried, especially considering the range of body mass and percent of body mass carried for participants in this study (54.9 kg – 89.8 kg; 31.1% of body mass – 50.9% of body mass). Further, the absolute load mass used in the current study may also explain the lack of consistency between the ESS and the PSS. The ESS was reported at 85% of PSS for 2 participants (25%), 90% of PSS for 3 participants (37.5%), 110% of PSS for 2 participants (25%), and 115% of PSS for 1 participant (12.5%). In walking, self-selected speeds are typically at or near the most economical speed (Ralston, 1958; Rose & Gamble, 2006). However, as seen in the current study, the ESS was consistently recorded at least 5% above or below the PSS. Again, these data may not be representative of the true economy curves for the shuffle since an alternative method was used to record the ESS compared to what has been previously used in the literature, but the differences in percent of body mass carried may explain the individual differences in the economy curves.

These data are inconclusive. Future research should replicate the methodology of this study for verification of the results with a larger sample size. It is difficult to determine if the difference in VO_2 was due to potential differences in the shuffle gait at the PSS and the ESS or due to the use of an absolute load mass rather than a load mass relative to body mass. Therefore, this study should also be duplicated with loads relative to body mass to better understand the physiological response to the shuffle gait. As the shuffle has not been thoroughly researched, it is possible that these results, seen as atypical when compared to walking or running, may be representative during the shuffle.

Practical Applications

Although the data are inconclusive, these results may indicate that a change in raw speed of as little as 0.3 kmh may be enough to significantly alter the economy of the shuffle gait. Based on these data, if a soldier opts to use the shuffle gait during a tactical march, the speed of the PSS is not different than the speed of the ESS. Therefore, despite the difference in VO_2 at these speeds, it is recommended that if the solider performs the shuffle, he or she should do so at his or her preferred speed since HR, RER, V_e, and RPE were not different between the PSS and the ESS. A point of importance for commanders and other leaders is that the absolute loads typically used in the Army may elicit significantly different responses across soldiers when performing the shuffle, resulting in early onset fatigue for some individuals. The shuffle should be used with caution, as it is critical for soldiers to maintain stamina for completion of the march and completion of the mission following the march.

CHAPTER V REFERENCES

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APPENDIX FOR STUDY III

APPENDIX A

IRB Approval Letter

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Tuesday, November 29, 2016

Investigator(s): Casey Clark (PI), and Dr. Jennifer Caputo (FA)
Investigator(s') Email(s): CBC4v@mtmail.mtsu.edu
Department: Exercise Science

Study Title: THE TACTICAL MARCH: QUANTIFICATION OF THE GAIT AND ECONOMY OF THEAIRBORNE SHUFFLE IN TORSO LOADED U.S. ARMY CADETS
Protocol ID: **17-2034**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(4) Collection of data through noninvasive procedures* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	APPROVED for one year from the date of this notification	
Date of expiration	**10/31/2017**	
Participant Size	50	
Participant Pool	18+ male MTSU ROTC MS-III and MS-IV cadets	
Exceptions	N/A	
Restrictions	**Musculoskeletal injury or high-risk individuals according to cardiovascular disease risk stratification. Females will also be excluded due to a small # of available females in the ROTC program**	
Comments	N/A	
Amendments	**Date**	**Post-approval Amendments**
	11/29/2016	1. Eric Scudamore is added as an investigator. 2. Revision of recruitment selection statement.

This protocol can be continued for up to THREE years (**10/31/2019**) by obtaining a continuation approval prior to **10/31/2017**. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Continuing Review Schedule:

Reporting Period	Requisition Deadline	IRB Comments

First year report	10/31/2017	INCOMPLETE
Second year report	10/31/2018	INCOMPLETE
Final report	10/31/2019	INCOMPLETE

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

Click here for a detailed list of the post-approval responsibilities.
More information on expedited procedures can be found here.

CHAPTER VI

OVERALL CONCLUSIONS

The purpose of this dissertation was to quantify the characteristics of the airborne shuffle as a gait modality and to examine the economy of the PSS in comparison to the PWS and the economy of the PSS to the ESS. Defining the gait characteristics of the airborne shuffle provided a basis for explaining physiological responses to this gait in the subsequent studies. Together, these studies provided a foundation to evalaute the efficacy of the airborne shuffle as a mode of locomotion during a tactical march compared to a standard, walking gait.

In Study 1, the characteristics of a walking gait and a shuffle gait while torso-loaded and unloaded at 3.0 mph were evaluated. Participants ($N = 11$) performed 4 randomized bouts (loaded walking, unloaded walking, loaded shuffle, and unloaded shuffle) while equipped with pressure sensing insoles (F-Scan) which digitally recorded temporal gait data. The shuffle resembles a walking gait, as FT did not occur during either of the shuffle trials. The effect of torso-loading was similar for walking and the airborne shuffle. However, the shuffle has a shorter SL, greater SF, shorter ST, shorter SWT, shorter SST, and shorter DST than a walking gait. As a shorter SL can decrease stress on the metatarsals, there is some justification for the use of the shuffle as a method of reducing lower limb stress during torso loaded tactical marches. However, previous research has shown the shuffle to be less economical at various speeds when compared to walking under torso load (Brenes et al., 2015).

In the second study in this dissertation, the PWS was compared to the PSS and the economy of the gaits at the preferred speeds while torso loaded was compared. Participants (*N* = 9) first completed trials designed to determine the PWS and the PSS. Following this, participants performed the walk or the shuffle at their respective preferred speeds for 6 minutes while physiological data were collected.

The PSS was significantly faster than the PWS. The faster shuffle speed likely explains the higher VO_2, HR, RER, V_e, and RPE, as any increase in the intensity of physical activity, such as an increase in speed, will increase the aerobic demand of ambulation. However, the economy of human walking also decreases with changes in stride length away from FCSL (Morgan et al., 1994; Morgan et al., 1989; Rose & Gamble, 2006). With deviations above or below FCSL, the aerobic demand of walking increases in a curvilinear fashion (Morgan et al., 1994; Morgan et al., 1989), with a greater increase in oxygen consumption when stride length is increased beyond FCSL (Morgan et al., 1994).

The alterations in the economy of movement associated with changes in stride length may have implications during the airborne shuffle, as the shuffle is a purposeful manipulation of gait away from a natural walking gait. With a shorter SL, the airborne shuffle, while torso-loaded, has been observed to be significantly less economical than walking while torso-loaded at speeds of 2.5, 3.0, and 3.5 mph (Brenes et al., 2015). Similarly, our data indicated that even at a self-selected, preferred speed, the shuffle was less economical than walking. The differences in gait between walking and shuffling were also likely a factor in the higher HR, RER, and V_e during the shuffle, as these physiological measures typically show a linear relationship with VO_2. Similarly, the greater perception of effort, as reflected by the higher RPE during the shuffle, was likely due to both the difference in the absolute intensity of the faster speed as well as the purposeful manipulation of the gait during the shuffle away from a normal walking gait. Therefore, the shuffle is not only less economical than walking, but is perceived as more difficult.

It has been reported that one of the reasons the airborne shuffle is used in the Army is that it is a method of decreasing lower limb stress during torso-loaded tactical marches (Brenes et al., 2015). Reduction of the incidence of lower limb injury is a significant concern as lower-extremity injuries are some of the most frequently occurring noncombat related musculoskeletal injuries (Kaufman et al., 2001; Liu, 2007; Ricciardi et al., 2008; Songer & LaPorte, 2000; Warr et al., 2015), particularly among recruits and infantry soldiers (Warr et al., 2015). However, potential reductions in the rate of injury must be weighed against alterations in economy of movement. Our findings indicate that the shuffle (at a self-selected, preferred speed) is a less economical method of movement than normal walking. Therefore, while it is possible that the shuffle may reduce stress on the lower limbs due to its shorter SL, it cannot be recommended for use over walking during tactical marches due to the higher metabolic cost and perception of effort.

The final study in the dissertation was designed to determine the ESS and compare it to the speed and economy of the PSS while torso loaded. The established method of determining a most economical speed (Horriuchi et al., 2015) could not be used with the current sample due to collinearity, possibly as a result of the small sample size. However, an alternative method was used to estimate the ESS by selecting the measured speed where economy was the lowest for each participant and comparing the data recorded at this speed and the PSS. Using this method, while VO_2 was lower at the ESS than at the PSS, the speed, HR, RER, V_e, and RPE were not different.

While not statistically different, speed was 0.3 kmh (4.9%) faster at the PSS (6.5 ± 0.7 kmh) than at the ESS (6.2 ± 1.2 kmh). It is possible that this difference in speed impacted the gait of the shuffle and altered the economy of movement. Correspondingly, the approximate 5% difference in speed may have led to an altered SL altering the economy of movement. The lack of differences and lack of consistency between responses for participants in HR, RER, Ve, and RPE suggests that, due to the absolute loads used, there may have been obfuscation in VO_2 values. With an increase in percent body mass carried during road marching, there are significant increases in HR, $\%VO_{2max}$, RER, V_e, and RPE (Beekley et al., 2007; Ricciardi et al., 2008). It is possible that the current data may be reflective of differences in physiological response to the absolute mass carried, especially considering the range of body mass and percent of body mass carried for participants in this study (54.9 kg – 89.8 kg; 31.1% of body mass – 50.9% of body mass).

Consequently, the data collected in Study 3 may or may not be indicative of true economy curves and the most economical speed for the shuffle. In the future, this study should be replicated with a larger sample size. Additionally, although real-world scenarios do not afford soldiers the opportunity to pack torso loads based on percent body mass, this study should also be replicated with both absolute and relative loads. There are still many unknowns about the human response to the shuffle gait. Without examining this gait at relative loads, it is difficult to provide conclusions as to what a typical economy response is to this gait. As the shuffle has not been thoroughly researched, it is possible that these results, seen as atypical when compared to walking or running, may be representative during the shuffle.

If a soldier opts to use the shuffle gait during a tactical march, the speed of the PSS is not different than the speed of the ESS. Therefore, despite the difference in VO_2 at these speeds, it is recommended that if the solider performs the shuffle, he or she should do so at his or her preferred speed since HR, RER, V_e, and RPE were not different between the PSS and the ESS. A point of importance for commanders and other leaders is that the absolute loads typically used in the Army may elicit significantly different responses across soldiers when performing the shuffle, resulting in early onset fatigue for some individuals. The shuffle should be used with caution, as it is critical for soldiers to maintain stamina for completion of the march and completion of the mission following the march.

In conclusion, while the shuffle gait is closer to a walking gait than a running gait, the gait characteristics are significantly and distinctly different between the walk and the shuffle. Further, due to these differences, the shuffle is less economical even at the preferred speed, which in other gaits, is typically not different from the most economical speed. However, the results of study 3, may indicate that the shuffle can elicit significantly different responses in regard to the economy of movement, even with changes in speed that are not statistically significant. While there may be some evidence to support the use of the shuffle as a method of decreasing lower limb stress consequent to the decreased stride length of the gait, there is not yet enough evidence to indicate that the benefits of stride reduction outweigh the negatives associated with the decreased economy during the shuffle gait. Completion of a tactical march in a timely manner while also maintaining the necessary energy to complete a mission or set up camp following the march is critical. Therefore, based on the results of these studies, it cannot be recommended that the shuffle gait be prioritized during tactical marches due to the less economical movement at both absolute speeds and at preferred speeds.

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