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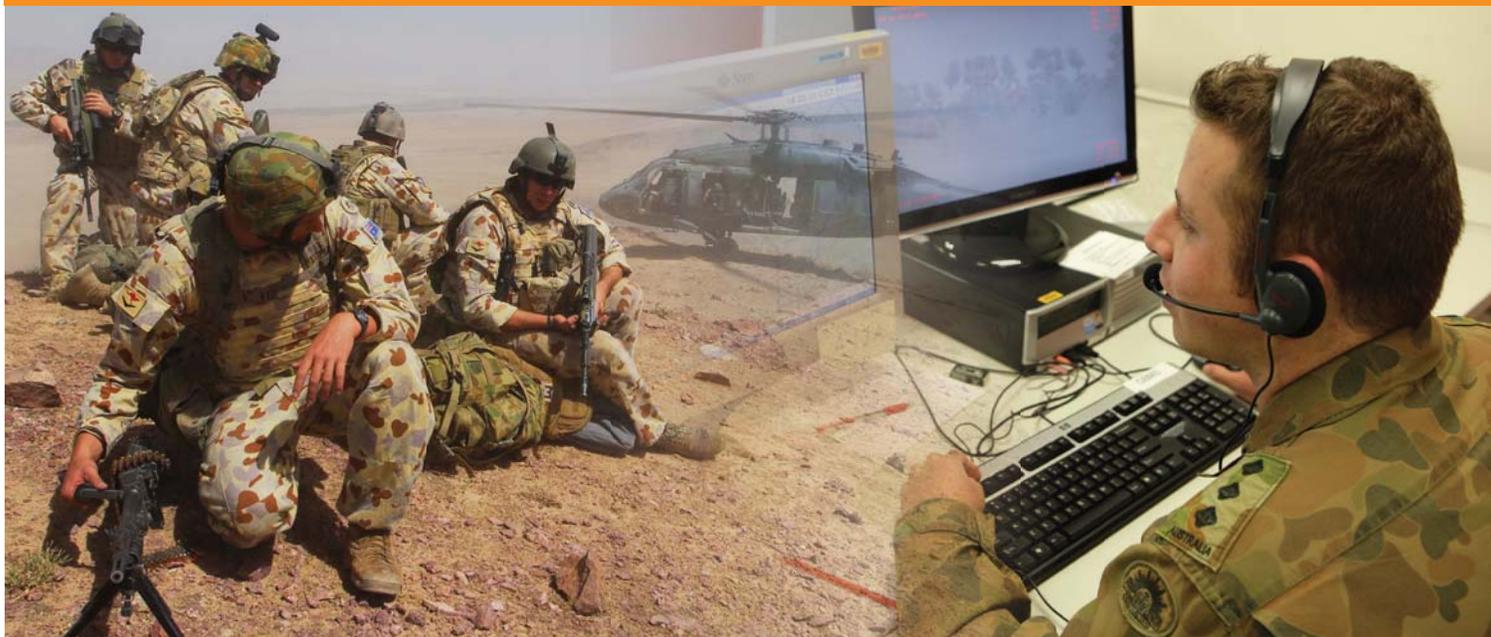


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Human Dimensions of Heavy Load Carriage

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ABSTRACT

There is a universal need for dismounted soldiers to be capable of moving their body mass plus an external load both administratively over a prolonged duration and tactically at high speed. A soldier's load is typically comprised of clothing, protective ensemble (i.e. body armour, helmet), combat equipment (i.e. webbing, weapon systems, ammunition, power sources, radio) and sustenance stores (i.e. food and water). The total load varies dependant upon factors such as mission requirements and threat profile. The U.S. Army have classified combat loads according as either fighting (or patrol) load (e.g. 18-22 kg), approach march load (e.g. 32-35 kg) and emergency approach (or sustenance) march load (e.g. > 35 kg). Whilst the combat loading terminologies and exact compositions may vary between the coalition armies, the purpose of the load is similar.

A dismounted soldier's load carriage capacity is influenced by a multitude of factors that can broadly be categorised into three main areas; soldier characteristics, mission requirements and context, and the load carriage system employed. Some of these factors may be manipulated to reduce the physical demands on the soldier, however this is ultimately dictated by the specific mission requirements and context. From a mission planning perspective it is important to appreciate the dynamic interaction and cumulative effects of these factors which impact individual load carriage capacity (and potentially battlefield performance) of the warfighter.

This paper will begin with a brief history of load carriage before discussing the important human dimensions of load carriage for the dismounted soldier. It is important to consider the modern history (i.e. 20th century) of military load carriage to appreciate the enduring nature of this problem and the demands placed on soldiers. Despite substantial advances in technology and logistics there remains a requirement for heavy load carriage. The discussion surrounding the human dimensions of load carriage has been divided into the two key dismounted soldier movement categories; a) administrative load carriage, and b) tactical load carriage. The reason for this dichotomy is that the potential consequences of heavy load carriage may be quite different for each movement category.

1. History of the Soldier's Load

1.1 Loads Carried Through the World Wars (1914 – 1945)

In the Great War, heavy loading of the foot soldier reduced the marching ability of the average soldier and was claimed to have altered the tactics of war [1]. The Battles of Cambrai and Amiens provide examples in which forward movement, limited by physical exertion, was reduced to 9 to 12 km per day (Lothian 1921).

During this conflict, the loads carried by Allied forces varied. French soldiers carried loads of up to 38.5 kg [2], with the specialised French Foreign Legion, claimed to have carried around 45.5 kg for up to 40 km per day [3]. The load carried by American troops, between 22 and 32 kg [4], or 34% to 50% body mass (BM) [5-7], were said to have left soldiers exhausted during short distance assaults between trenches, even before contact with the enemy [7]. While British soldier loads started lighter (20.5 to 27 kg) [1, 8] they soon increased and towards the end of the war they carried loads of between 30 to 40 kg [1, 2, 8-12] or around 50% to 57.5% BM [2]. The Canadian and Australian soldiers carried equivalent loads with Canadian soldiers carrying between 30 and 36 kg [13, 14] and Australian soldiers between 27 and 33.5 kg [15, 16]. Conversely, German troops carried loads ranging from 25 to 45.5 kg, although loads averaged 32 kg [2, 17].

Little changed leading into the Second World War. During the D-Day landings at Omaha Beach, American troops charged through chest deep water, and then across sands, all while exposed to heavy enemy fire with loads of around 27.5 to 41 kg [4, 18-20], or 41.6% to 62.5% of BM [21]. It is of little wonder that these loads were attributed with causing deaths in the water

[20]. Canadian and British soldiers carried similar loads [22].

Meanwhile, on the Eastern Front, Russian soldiers carried loads of between 28 and 35.5 kg [23], while in the North African desert, Australian troops carried loads of between 22 and 32 kg into the battles at Bardia and El Alamein (1941 – 1942) [24, 25]. In the Pacific Theatre, Australian soldiers carried similar loads ranging from 20.5 to 41 kg in Papua New Guinea (1942) [26-28] and up to 37.5 kg in Borneo (1945) [29]. Their adversaries, the Japanese soldier, also carried heavy loads, ranging from the standard 28 kg up to 56 kg for machine gun units. For the lightly built Japanese soldier this equated to a load of between 52% and a staggering 105% BM [30-32].

1.2 Loads Carried Through Modern Conflicts (1950 – Present)

During the Korean War, American loads rose from 18 to 22.5 kg up to 37.5 kg [33, 34] with American Marines reportedly carrying around 55 kg through the snows and steep slopes of Toktong Ridge [35]. While soldiers of the Republic of Korea's Army likewise carried loads of over 36.5 kg [36], the North Korean Peoples Army (NKPA) and the Chinese Communist Forces (CCF) carried noticeably lighter loads of around 18.5 kg and were able to move faster and further per day than their American counterparts [34].

During the Vietnam War (1959 – 1975), the typical load for the American infantry soldier was between 27.5 kg and 32 kg [37-39] and for the Marines more likely 36.5 to 45.5 kg [40]. Australian soldiers generally carried heavier loads of between 30 and 40 kg for a rifleman and up to 47.5 to 56 kg for radio operators [28, 41-43]. Several members from the 8th Battalion, Royal Australian Regiment (RAR), who weighed their packs found themselves carrying loads of between 36.5 and 54 kg [44]. Interestingly, even when their mission

changed from reconnaissance to pacification, and the nature of the loads changed, the overall load weight remained the same (Hall, 2000).

The native Viet Cong were not so encumbered. Unlike the heavy loads carried by soldiers from foreign forces, the Viet Cong reportedly carried noticeably lighter loads of around 12 kg [45]. These loads were perhaps indicative of the benefits of fighting on 'own' soil.

During the Falklands conflict in 1982, the British infantry and Royal Marines carried loads between 32 to 36.5 kg in fighting order and 45.5 to 54.5 kg in marching order [4, 28]. In a well known 'yomp', the 45 Royal Commando Marines carried a load of between 54.5 and 66 kg across a distance of 129 km [4, 46-48]. A year later, American troops landed in Grenada on Operation URGENT FURY. Loads, ranging from 54.5 kg [20] to an astounding 76 kg for Army Rangers parachuting onto the runway at Salina's airfield [3], had some soldiers sidelined and on intravenous therapy bags due to being overloaded during the assault to secure an airhead. Just over a decade later US soldiers landed in Somalia. Coming ashore on Operation UNITED SHIELD, US infantry soldiers carried loads of around 49.5 kg or 70% BM [49].

In East Timor, on Operation CITADEL, Australian soldiers carried loads in excess of 45 kg, with gunners and signallers carrying loads in excess of 50 kg. The load of their webbing and body armour were thought to hinder Australian soldiers chasing fleeing militia [50].

During Operation DESERT SHIELD and DESERT STORM, American soldiers carried loads of up to 45.5 kg [22] and continued to carry loads between 45.5 to 54.5 kg in Iraq and Afghanistan [4, 51, 52]. A recent comprehensive study of the 82nd Airborne Division, on Operation ENDURING FREEDOM III in Afghanistan, found that the soldier's carried

a fighting load of 29 kg, an approach march load of 43.5 kg, and an emergency approach march load of 57.5 kg or 36%, 55% and 73% body mass respectively [53].

Where the soldier's protective and lethality equipment and sustainment stores have changed; the soldier's load has not reduced. Where logistical and technological transport aids have changed over the last two millennia; the soldier's load has not reduced. Even where the nature of warfare has changed, from converging phalanxes and trench warfare to today's complex battlefield; the soldier's load has not reduced. History therefore suggests that relying on improved load carriage logistical aids and changes to equipment may not be the sole answer to this age old problem.

2. Adverse Health Outcomes of Heavy Load Carriage

The level of load carriage exposure and a soldier's risk profile influence susceptibility to a load carriage injury. The risk of injury increases with the magnitude of load carriage exposure, i.e. increased weight, increased marching duration or increased frequency. With regards to the soldiers' injury risk profile, low or high levels of joint flexibility, low muscular strength or aerobic fitness, smoking and alcohol consumption are all linked with increased incidence of load carriage related injury [54, 55]. However, the primary risk factor for injury in both males and females is aerobic fitness [54-56].

The most common acute load carriage injuries are blisters and back pain [57, 58]. In a study where soldiers undertook strenuous load carriage (20 km with 45 kg load), 50% of the soldiers who were unable to complete the march cited back related problems [57]. The risk of back pain as a result of prolonged load carriage appears to increase with increasing external loads and

has been attributed to the amplified forces on the spine [58-60]. Increased external loads also increase trunk forward lean and ground reaction forces and alter walking gait which may further augment stress on the back [60-64]. Changes in spinal curvature in response to acute loaded walking have also been observed [65, 66]. Repeated load carriage exposure may therefore lead to morphological changes in the spine.

Brachial plexus palsy or "Rucksack palsy" is another common shoulder condition associated with load carriage [67]. It is proposed that this injury is caused by traction and or compression of the C5 and C6 nerve roots of the brachial plexus by the load carriage system shoulder straps [67]. Typical symptoms include numbness, pain and weakness of the upper extremity. Again, increased external load appears to increase the risk of this condition [59].

Evidence suggests the cumulative effect of heavy load carriage likely contributes to stress fractures of the lower limb and intervertebral disc injury. A recent review by the Australian Defence Force (ADF) Army Recruit Training Centre (ARTC) showed that lower limb stress fractures accounted for more than 50% of total time lost to injury in the period 2005-2007. Marching accounted for the greatest percentage of these lower limb stress fractures. Susceptibility is greater in females, tall individuals and those of a white ethnic background. However, a lack of physical conditioning appears to be the greatest risk factor as evidenced by the high incidence of lower limb stress fracture injuries amongst military recruits [68].

3. Administrative Load Carriage

Administrative load carriage is defined as prolonged (e.g. 5 - 20 km) moderate intensity (e.g. 3 - 6 km/hr) loaded marching. The combat loads typically carried by

soldiers for administrative movements are marching loads (approach and emergency), with total weight typically exceeding 30 kg. Under these load carriage conditions physical stress can manifest in a variety of forms, and the main factors influencing load carriage capacity are discussed below.

3.1 Total External Load

It is well-established that an increase in external load weight increases the energy cost of load carriage [69-71]. Numerous studies [69-73] have described a linear increase in energy cost with increased pack weight. Regardless of the precise nature of this relationship, a weight load threshold exists beyond which capability is significantly degraded [74].

Epstein et al. [75] suggests that maximal load carriage efficiency (as determined by energy expenditure) is achieved at 4.5-5.0 km/hr walking speed with a load weighing 40-50% of body mass. Such guidelines, whilst informative, must be interpreted with caution. Walking speed, walking surface gradient and walking surface characteristics (e.g. asphalt, loose sand) along with external load, are equally important determinants of the energy cost of load carriage. Figure 1 demonstrates four different load carriage scenarios with an equivalent energy cost.

March performance (i.e. time to complete distance) has also been shown to diminish with increasing external load [76-79]. Perhaps less well understood and/or appreciated are the psychological effects of loaded marching. An early study by Johnson and Knapik [80] showed that in response to prolonged (20 km) load carriage, mental alertness and feelings of wellbeing diminished with increasing load (34 to 61 kg). These results have potential implications for the operational effectiveness of soldiers as mental fatigue has been shown to diminish exercise tolerance in civilians with physical characteristics similar to numerous reported military populations [81].

3.2 Load Distribution

The distribution of external load has been shown to influence energy cost and load carriage capacity. It is well established that loads distributed close to an individuals centre of mass minimises postural disturbances and results in decreased energy expenditure [67, 82, 83]. Knapik et al. [67] reported that every 1 kg added to the foot increased energy expenditure by 7-10% and that every 1 kg added to the thigh increased energy expenditure by 4%. For the soldier, load may be distributed to the head (helmet, night vision goggles), trunk (webbing, pack, body armour), hips/thigh (webbing, weapon), hands (weapon) and feet (boots). For load carriage on flat, firm surfaces evidence suggests loads should be

the individual warfighter. However, perhaps more importantly Commanders and soldiers need to carefully consider risks versus benefits when making decisions about equipment taken on missions and how and where it is carried.

3.3 Speed

For the soldier, the speed of load carriage (i.e. marching speed) is largely dictated by mission requirements. Administrative (i.e. non-tactical) tasks are typically undertaken at a moderate pace (i.e. 3.0-6.0 km/hr) whilst tactical tasks may involve movement at various speeds from slow walking to sprinting. An increase in speed for a given load will increase the energy cost of the activity [72, 73, 85-87]. Figure 2 provides

a

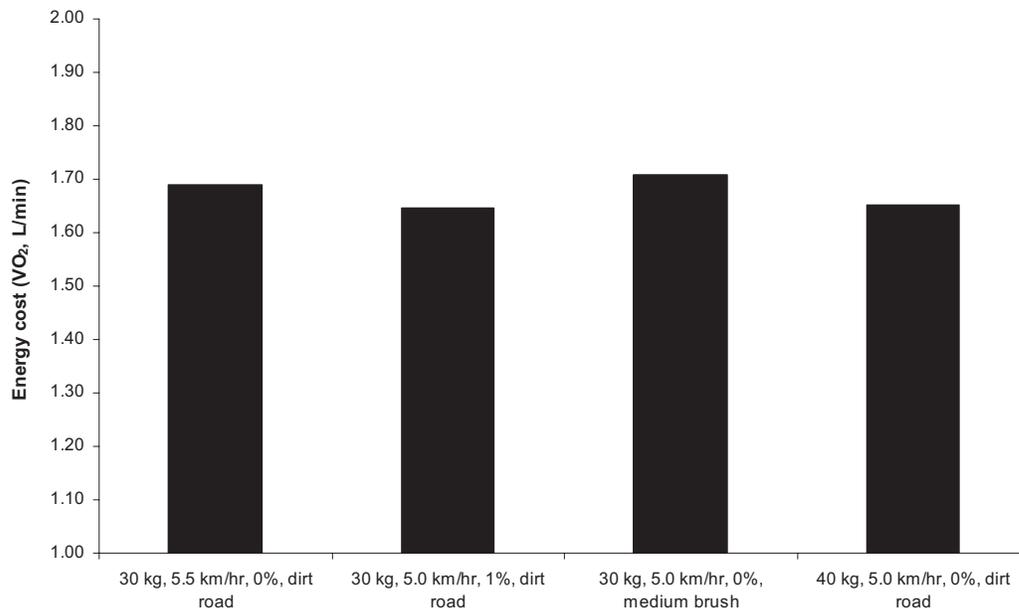


Figure 1: Energy cost of different load carriage scenarios predicted using the equation of Pandolf et al. (1977).

positioned high on the back [67, 84]. With elevated and/or uneven terrain, loads should be spread over the length of the back [67]. Modifications to equipment and/or redistribution of weight around the bodies' centre of mass are potentially important for

representation of increased energy costs associated with increased walking speed, when all other variables are held constant. Assuming that all other variables are held constant, an increase in walking speed of 0.5 km/hr illicit an increase in (predicted)

energy cost equivalent to a 10 kg increase in external load [85].

3.4 Distance and Duration

The duration of load carriage can range from minutes to hours, potentially over consecutive days. The combination of duration or distance of load carriage along with walking speed and total external load primarily influence soldier load carriage capacity. It is important to understand that work duration and intensity (i.e. walking speed and external load) are inversely proportional. For example the energy cost of marching with a 50 kg load at 4.2 km/hr is similar to marching with a 35 kg load at 5.0 km/hr [88]. Put simply, this means the harder a soldier works, the shorter the duration the task can be sustained. Climate, terrain and soldier characteristics also contribute to soldier load carriage capacity. If the demands (i.e. external load, environmental) of a mission cannot be altered, the use of rest breaks can assist in delaying and/or preventing fatigue and possible decrements in operational capacity.

Some studies [75, 89] but not all [69, 90] have shown that the energy cost of load carriage progressively increases during prolonged (i.e. > 120 min) walking. A similar increase in the cardiovascular demands during prolonged exercise (known as “cardiovascular drift”) is well described [91]. It appears that increased external weight and faster walking speeds augment the progressive increase in energy cost during prolonged load carriage [75, 89].

Self-paced studies have demonstrated that subjects are able to assess the physiological burden of a task and adjust work rate accordingly to maintain a relatively constant intensity. During self-paced prolonged load carriage (all other variables held constant), walking speed decreased over time due to increasing energy costs [76, 92]. It is suggested the decrease in walking speed offsets the progressive upward drift in energy cost of load carriage to maintain the same relative work intensity (i.e. % maximal oxygen uptake, VO_{2max}). Similarly, Knapik [76] showed that soldiers decreased walking speed during a 20 km road march with increasing external

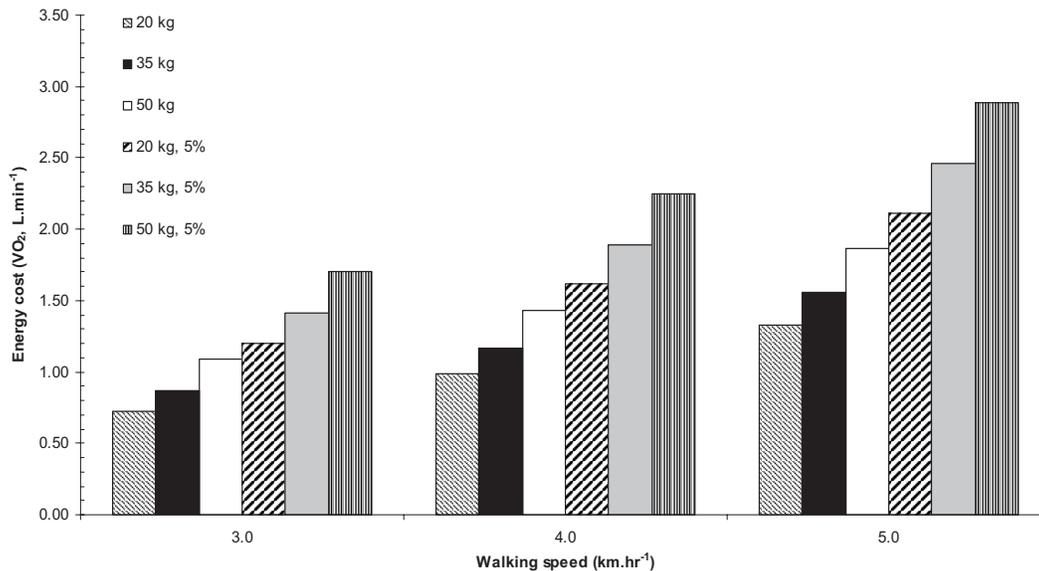


Figure 2 : Energy cost of flat and graded (5%) load carriage on a dirt road with different external loads predicted using the equation of Pandolf et al. (1977).

loads (34 to 61 kg). Interestingly, the decrease in walking speed with increasing external load resulted in a reduced energy expenditure. This would indicate that metabolic workload is not the sole determinant of self-selected work intensity (i.e. walking speed), and other factors (e.g. shoulder discomfort) may become more important with increasing external loads (discussed further in 3.12).

3.5 Terrain

Soldiers may be required to carry loads in a variety of environments (jungles, hills, deserts) which may influence load carriage capacity. The gradient (e.g. flat, incline, decline) and surface characteristics (e.g. bitumen, sand, swamp) of the terrain are important factors when considering load carriage capacity and energy cost.

It is well established that the energy cost of load carriage increases when walking up inclined terrain, compared to flat walking [71, 93, 94]. Charteris [94] showed that the energy cost of load carriage approximately doubled when walking at 4 and 5 km/hr at a 10% gradient compared to level walking. Furthermore evidence suggests a 1% increase in surface gradient increases energy expenditure equivalent to a 10 kg increase in external load [71, 85, 93]. Figure 2 demonstrates the predicted increase in energy cost of uphill (5%) load carriage across a range of loads and walking speeds. Decline gradients have also been shown to increase the energy cost of load carriage compared to flat walking, but not as much as inclined walking [95, 96].

With respect to surface characteristics of the terrain, Soule and Goldman [97] developed coefficients indicating the relative energy cost of walking across various terrains with loads ranging from 10 to 40 kg. The order of least to most demanding walking surfaces is as follows; blacktop (asphalt), dirt road, light brush,

heavy brush, swampy bog and loose sand. The predicted energy cost of load carriage would almost double if the surface changed from a dirt road to loose sand and all other variables (walking speed, load and gradient) were held constant.

3.6 Climate

Climatic conditions (e.g. temperature, humidity, rainfall, snow) can impact significantly upon the physiological burden of load carriage. High ambient temperature and high humidity can both increase the thermoregulatory stress associated with work (i.e. load carriage) and may reduce load carriage capacity. Work in hot environments may increase dietary carbohydrate and or fluid requirements.

The metabolic heat generated during load carriage in a thermo-neutral environment can be sufficient to cause considerable heat stress. Undertaking work (i.e. load carriage tasks) in hot and/or humid conditions further increases the thermal challenge of load carriage and may diminish soldier load carriage capacity. Counter-measures such as decreased work-rates or increased rest periods may be required to enable or prolong safe work. Dehydration can further impair both physical performance and tolerance to hot environments.

During cold stress, basal metabolic rate can increase to intensities equivalent to approximately 40% VO_2max due to shivering thermogenesis [98]. The energetic cost of maintaining thermal balance in a cold environment can represent a considerable additional metabolic load on the body [99]. Furthermore an increase in heat production through shivering can accelerate the depletion of carbohydrate stores [100]. Shivering during load carriage is unlikely due to metabolic heat production. However waiting several hours for an IED to be disarmed may be sufficient to induce shivering.

Cold weather and rainfall can also impact on the energy cost of load carriage and load carriage capacity of the soldier. Rainfall and snow can alter the surface characteristics of the terrain (e.g. mud, water, snow) and increase the clothing and equipment burden. Studies investigating energy requirements in military populations have suggested increased energy requirements during cold conditions [101-103]. An increase in the weight and/or bulk of clothing and equipment carried by soldiers and winter terrain (e.g. snow, mud) can increase energy expenditure [97, 104]. Two studies investigating energy expenditure in moderately active soldiers in cold environments (mean temperature -18°C to -22°C) have shown similar findings, with energy expenditure found to be approximately 18 MJ per day [105, 106]. In line with these findings the current U.S. Military recommended dietary allowance for males in environments that are colder than 14°C is 18.9 MJ per day. Insufficient food intake may in fact be a greater issue for soldiers in cold environments than increased energy requirements. Increased palatability of rations and/or supplemental ration packs may be options to ensure soldiers are adequately nourished whilst on operations in cold environments.

3.7 Altitude

As we ascend in elevation above sea-level the atmospheric oxygen levels decline which may reduce physical work capacity. It is suggested this effect becomes more evident at elevations above 1500 m [107]. Altitude can also increase fluid loss (compared to sea-level) so care must be taken to ensure adequate fluids are consumed. Due to the decreased oxygen availability work rates should be adjusted (reduced). Repeated exposure to this environment will lead to physiological adaptations (acclimatisation) that improve an individual's ability to work at altitude. Increased aerobic fitness will increase an

individual's ability to cope with work at altitude.

3.8 Nutritional Requirements

Load carriage demands (i.e. external load, marching speed, march distance) together with environmental conditions (i.e. climate, terrain) determine the soldier's nutritional requirements. Studies have demonstrated that soldiers' daily energy expenditure can range from 12 to 28 MJ [108]. The upper end of this energy expenditure range rivals the energy expenditure observed in the Tour de France and Ironman triathlons. A number of studies that have measured energy expenditures of soldiers undertaking tasks commonly performed by dismounted soldiers have observed average daily energy expenditures in the range of 15 to 19 MJ [109-111]. Combat Rations typically provide 15.5 MJ [112] and these results suggest that this may be inadequate for some prolonged and/or intense operations requiring load carriage. Soldiers may therefore require supplementation to meet energy requirements under such conditions. Inadequate nutritional recovery from prior tasks may also decrease a soldier's work capacity and increase susceptibility to injury on subsequent days.

Regular consumption of fluid is critical to soldier health and performance as dehydration has been shown to impair both physical performance and tolerance to hot environments. A decrease in body mass of as little as 2% can degrade both physical and mental performance and increase susceptibility to heat injury. Decreased attention and vigilance as well as decreased ability to perform complex mental processing tasks have also been observed with dehydration. Average sweat rates for infantry soldiers during operations in hot-dry and hot-humid conditions have been shown to be 1.0-1.7 L.hr⁻¹ [108, 113]. Based on these results the fluid requirements for soldiers undertaking prolonged load carriage (e.g. 6-8 hr patrols) in hot conditions (> 30°C) may be in excess

of 10 litres (10 kg). Every kilogram of weight (i.e. litre of water) added to the soldier increases the load carriage requirement and subsequently the physiological burden. It is important that fluid (i.e. water) consumption does not exceed sweat loss. Over consumption of water can lead to a potentially fatal condition known as hyponatraemia. Hyponatraemia has been reported in soldiers undertaking basic training and prolonged marching [114, 115].

3.9 Soldier Characteristics

Evidence suggests certain physical characteristics are more favourable to load carriage performance. Body mass, fat free mass, absolute muscular strength and absolute VO_2max have been identified as predictors of load carriage capacity [116-121]. Several studies have demonstrated superior performance in load carriage tasks in heavier individuals, when compared to lighter individuals [77, 116, 122]. It is assumed that a larger body mass is associated with a larger muscle mass resulting in greater absolute strength. This is pertinent to gender differences in load carriage capacity as females have on average lower body mass and lower relative muscle mass compared to males. However this assumption should be used with caution as research suggests that the correlation between body composition (i.e. % fat free mass) and body mass is weak. Furthermore current evidence suggests that western societies are increasing in both body mass and body fat due to increased caloric intakes and reduced physical activity.

3.10 Soldier Training and Load Carriage

Research has demonstrated that load carriage capacity can be enhanced with appropriate physical conditioning. Repeated exposure to walking with backpack loads has been shown to decrease the energy cost of load carriage [67] and

increase aerobic fitness [123]. With respect to general physical training, programs that involve a combination of aerobic training (running) and strength training appear to be most successful in improving load carriage capacity, compared to training either component of fitness alone [67, 122, 124]. The improvement in load carriage performance from the combined training was attributed to improvements in both upper body strength and aerobic fitness. Furthermore the combination of loaded marching together with aerobic and resistance training improved load carriage performance more than aerobic and resistance training alone [125, 126]. With regard to the frequency of soldier training sessions, evidence suggests that loaded marching should be undertaken two to four times per month under operationally relevant conditions [67, 125, 127, 128]. Both high load-short distance and moderate load-long distance training have been shown to improve loaded marching performance [125, 127]. Load carriage training (e.g. load, speed, distance, frequency) should consider individual soldier characteristics and experience to mitigate the incidence of load carriage injuries (e.g. stress fractures).

3.11 Biomechanical Considerations

As with physiological consequences, the biomechanical consequences of prolonged load carriage are affected by a multitude of variables (e.g. walking speed, distance, terrain, total load, load distribution, load carriage equipment, soldier characteristics).

Short term (< 20 min) load carriage of up to 36 kg results in minimal change in posture and gait [129-131].

Studies investigating more prolonged load carriage have observed alterations in ground reaction forces, lower limb joint angles, increased forward lean, decreased stride length, increased stride frequency and increased duration of the double support phase [57, 61, 63, 64, 132]. Similar to

increased march duration, increased external load is also associated with an increase in forward lean, ground reaction forces and muscle activity [133-138]. It is also suggested as load increases so to does the risk of back injury [139]. Changes in posture, joint angles and gait may increase fatigue and the potential for injury [62].

3.12 Load Carriage Integration

Poor load carriage equipment integration may be a major limiting factor in load carriage capacity. As previously mentioned, blisters and back pain are commonly observed during military load carriage [57, 68]. Discomfort associated with blisters or lower back pain can lead to postural and biomechanical alterations which can decrease gait efficiency (i.e. increase energy expenditure) and increase susceptibility to injury. Changes to the load distribution (e.g. backpack v. front-back pack) have been shown to decrease blister likelihood [76].

Large increases in subjective discomfort, particularly in the shoulder and neck region, have also been observed under prolonged load carriage conditions [76, 77]. Evidence suggests that upper body discomfort and muscle stress (e.g. rucksack palsy) may become a limiting factor during prolonged load carriage [61]. A decrease in grenade throwing performance following loaded marching has been attributed, at least in part, to shoulder discomfort (i.e. rucksack palsy). Shoulder discomfort is caused not only by the magnitude of pressure associated with an external load but also the exposure time. Therefore shoulder discomfort may become the limiting factor under low to moderate intensity prolonged load carriage. Load carriage equipment that transfers some of the load from the shoulders to the waist has been shown to reduce shoulder discomfort and improve soldier performance [59, 140].

Weight load, march duration, load distribution, terrain and soldier fitness together with load carriage equipment

design contribute to the incidence of acute load carriage injuries [57, 141, 142]. Load carriage equipment integration (or lack thereof) with the platform (i.e. soldier) plays a significant role in load carriage tolerance and battlefield performance of the dismounted soldier.

4. Tactical Load Carriage

Tactical load carriage for the purpose of this discussion is defined as short to moderate distance (i.e. < 5 km), slow to maximal movement speed (2 km/hr to sprinting). Whilst administrative movements could be described as aerobic activities, tactical movements can be aerobic and or anaerobic activities, depending upon the level of enemy engagement. Tactical movements are typically completed in a fighting load ranging from 20-35 kg. Examples of these movements may include tracking and engaging the enemy, section attacks and breaking contact.

Soldier physical mobility limitations, more so than fatigue per se, are considered the main factors limiting tactical movement. The primary factors potentially contributing to reduced tactical movement capacity are discussed below. It must be emphasised however that we cannot discount physiological factors discussed with respect to administrative movements contributing to decreased tactical performance. For example the effects of prior tasks (e.g. prolonged load carriage) may deplete energy stores, induce muscle fatigue, increase heat storage or diminish cognitive performance, all of which can decrease physical (i.e. tactical) performance. In line with this, Lieberman [143] demonstrated that a modest energy deficit over the course of a single day of combat training led to a significant decrease in cognitive performance. Similarly a 53 hr combat training exercise that combined sleep loss with physical, nutritional, psychological and heat stress demonstrated a substantial

degradation of cognitive performance [144]. The cognitive performance of a soldier potentially impacts upon their physical mobility, lethality and survivability.

4.1 Mobility

Intuitively it would appear logical that as external load increases there would be an associated decrease in mobility on the battlefield. Interestingly, it was noted almost 100 years ago that “the fighting value of a soldier is in inverse proportion to the load he carries”. In fact it is suggested that army tactics were changed during the First World War in response to a load induced reduction in soldier mobility [1]. Studies have shown that external load can affect performance of key military tasks and thus compromise mobility when compared to an unloaded state. Holewijn et al. [145] demonstrated that for every 1 kg increase in external load, there was an average performance loss of 1% during tasks including jumping, sprinting and obstacle course completion. A recent investigation [146] demonstrated an average decrease of 1.5% in soldier performance for every 1 kg increase in a load range of 19.1 to 29.2 kg across five mobility assessments. The assessment tasks included an agility course, sprinting, jumping, stand and reach balance and a simulated section attack.

Obstacle courses have been used extensively within military performance studies, with a large number of studies showing an increased time to complete the course with increased load [78, 117, 145, 147-149]. A meta-analysis conducted by the U.S. Army Research Laboratory showed a significant linear relationship between total load and obstacle course completion time [149].

Load distribution and physical mobility has been investigated with equivocal results. Derrick [79] showed no significant difference between upper and whole torso

load distribution on soldier mobility. In contrast, Holewijn [145] observed varying results across a series of mobility assessments when weight was distributed around the waist, lower back and upper back. For example weight on the lower back (compared to upper back) was detrimental to obstacle course performance yet resulted in better performance in vertical jump and sprint performance.

The relationship between load carriage and physical mobility is complicated by the actual overall load, how it is distributed on the body and the physical space taken up by the load, the task being undertaken, and the physical characteristics of the soldiers.

4.2 Lethality

Load carriage activities may impact upon soldier lethality as it has been shown that marksmanship performance can decrease following load carriage tasks [150, 151]. A load carriage induced decrease in marksmanship may be explained by a reduced ability to stabilise the weapon when firing due to muscle fatigue, elevated respiration, elevated heart rate or increased hand tremors [150, 151]. Not all studies have found a decrease in marksmanship following load carriage [76, 152]. The conflicting results between studies may be attributable to differences in time between the completion of a loaded march (pre-fatiguing task) and the commencement of the marksmanship assessment. Longer time periods between the march and firing assessments allow for greater recovery from the physiological stress associated with loaded marching (e.g. decreased heart rate and decreased hand tremors) [153, 154]. Some studies [77, 145], but not all [76, 150] have demonstrated a decrement in grenade throwing performance (i.e. distance) following load carriage activities.

4.3 Survivability

Mahoney et al. [155] observed that, when walking with a 40 kg load, soldiers vigilance decreased (when compared to an unloaded state). The decrement in vigilance task performance was further exacerbated when walking involved obstacle avoidance. The results also showed a greater decrement in vigilance task performance in response to tactile and visual stimuli compared to auditory. These results suggest that soldiers, when carrying heavy loads, are more likely to overlook or misinterpret visual cues when patrolling and visually scanning for enemy and threats (e.g. IEDs). More recently May et al. [156] investigated the impact of a backpack load (30% BM) on decision making ability in response to auditory stimuli. The results demonstrated that a backpack load degraded mental processing as evidenced by increased reaction time and response error.

5. Recommendations and Conclusion

The multi-factorial nature of human load carriage capacity makes it difficult to provide definitive guidelines. Furthermore setting maximum load limits (either relative or absolute) or maximum intensity limits may be difficult to implement in the field and may not always be operationally possible. It is understood that mission requirements, operational constraints and threat profile dictate load carriage requirements. However the commanders' mission planning needs to balance, to some degree, the requirements of the operational environment against the various physiological considerations of soldier load carriage. Therefore commanders (and soldiers) need to understand the physiological impact of various load carriage variables on individual load carriage capacity and operational effectiveness.

A series of evidence-based guidelines for military load carriage are provided below summarising the existing research on the human dimensions of load carriage. These recommendations are based on the assumption that soldiers are adequately nourished, hydrated and rested prior to undertaking administrative load carriage.

5.1 Administrative Load Carriage

External Load

- Appears to be small differences in energy cost of load carriage with low to moderate external load (e.g. 20 to 40 kg) within a walking speed range of 3.5-6.5 km/hr over flat terrain.
- Energy cost associated with a 10 kg increase in external load is equivalent to an increase in walking speed of 0.5 km/hr or an increase in gradient of 1%.

Walking Speed

- Walking speed exerts a greater effect on energy expenditure than external load. The energy cost associated with an increase in walking speed of 0.5 km/hr is equivalent to an increase in external load of 10 kg.
- Most energy efficient walking speed is within the range of 3.2-5.0 km/hr with a load up to 47 kg.
- Optimal walking speed is inversely related to the weight of the load (i.e. heavier load = slower speed, lighter load = faster speed).

Marching Distance

- Progressive increase in the energy cost of load carriage over time with heavy loads (i.e. ≥ 40 kg) and/or faster walking speeds (i.e. ≥ 4.5 km/hr).

Terrain

- 1% increase in gradient increases energy expenditure equivalent to a 0.5 km/hr increase in walking speed or a 10 kg increase in external load.
- The increased energy cost of walking through medium scrub (compared to asphalt) is equivalent to a 0.5 km/hr increase in walking speed or a 10 kg increase in external load.
- Loose sand doubles the energy cost for a given walking speed and load compared to a hard flat surface such as asphalt.

Climate

- Hot conditions and altitude increase fluid requirements.
- Increased water loads should be carefully considered as increased total load may further increase fluid requirements.
- Cold conditions may increase energy requirements however this is dependant upon activity levels and changes to clothing and equipment.

Load Distribution

- External loads distributed close to the soldiers centre of mass (torso) reduce energy cost of load carriage - peripheral loads (i.e. hands, feet, legs) should be reduced to essential equipment.
- Loads should be positioned higher on the back for load carriage on flat, firm surfaces but distributed more evenly across the back when marching on uneven or uphill terrain.
- The distribution of the load should be laterally symmetrical.

- Packs that distribute more of the load to the hips (i.e. away from the shoulders) are recommended.

5.2 Tactical Load Carriage

Load

- Linear relationship between increased load and decreased physical mobility.
- Increasing external loads may accelerate fatigue during prolonged tactical movements.
- Backpack load has been shown to decrease vigilance and mental processing ability.

Distance / Duration

- Tactical performance (e.g. mobility, marksmanship) may be reduced by pre-fatigue or accumulated heat load from preceding work (i.e. loaded march). Cognitive performance in tactical situations may also be reduced by previous or sustained work.

Fluid Requirements

- High intensity tactical movements are associated with high metabolic heat production, therefore sufficient fluid intake is required to minimise the thermal burden.
- Dehydration has been shown to not only decrease physical performance but also decrease cognitive ability, which is critical to tactical performance.

Load Distribution

- Research is unclear on ideal torso load distribution, appears to be task dependant.
- Peripheral loads (i.e. hands, feet, legs) should be reduced to operationally essential equipment.

Load Carriage Equipment

- Load carriage equipment may reduce soldier lethality through upper body discomfort and rucksack palsy.

5.3 Further Considerations

With regard to establishing maximum load limits it must be emphasised that operational loads should not be set as a percentage of soldier's body mass. Military load carriage studies consistently express external weight loads relative to body mass. This is useful in understanding the effect of external load on various physical parameters such as the external weight load threshold. However reporting external weight load as a relative rather than absolute weight is not relevant to military operations. Whilst there may be the capacity to share section equipment this distribution is typically determined by occupational specialty rather than body mass. That being said, setting load as a % of BM may be of use for the purposes of progressive and structured physical conditioning of soldiers for load carriage tasks. In a controlled training environment, free from the influence of operational requirements, loads (% BM) can be progressively increased towards an absolute (operationally relevant) end-point load. Progressive load carriage conditioning will likely optimise physical adaptations and reduce the incidence of injury.

Research clearly supports load carriage training prior to deployment. Load carriage conditioning will improve soldier performance and decrease the likelihood of adverse health outcomes (acute and chronic injury). Ideally load carriage conditioning will reflect expected operational load carriage requirements.

Defence and Industry are currently exploring material and technology innovations to reduce the total weight load. It is critical that equipment integration with the soldier is a primary consideration in this

process as evidence suggests that poor load carriage equipment integration may be a limiting factor in prolonged load carriage.

The logistical support of the dismounted soldier is another important consideration. Whether it is an inadequate re-supply chain or a lack of soldier confidence in the re-supply chain due to a historical hangover, the net effect is an increased physical burden on the dismounted soldier.

6. References

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