Chapter 3 – COMMON MILITARY TASK: MARCHING

by

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3.1 INTRODUCTION

"On the field of battle man is not only a thinking animal, he is a beast of burden. He is given great weights to carry. But unlike the mule, the jeep, or any other carrier, his chief function in war does not begin until the time he delivers that burden to the appointed ground." (Marshall, 1950)

Foot marches can be defined as the movement of troops and equipment mainly by foot with limited support by vehicles. They are characterized by combat readiness, ease of control, adaptability to terrain, slow rate of movement, and increased personnel fatigue. A successful foot march is when troops arrive at their destination at the prescribed time and are physically able to execute their mission (Department of the Army, 1990).

Many NATO nations have soldier modernization programs that aim to equip soldiers with fully-integrated state-of-the-art technologies that will enhance the five NATO soldier capability areas: lethality, protection, mobility, sustainability, and command and control. Military carriage capacity can have an impact on a number of these capabilities areas. In particular, it is critical to soldiers mobility and sustainability, and ultimately, to soldier performance and survival on the battlefield (Leeuw, 1998).

Mobility is defined as the capability of the dismounted soldier to traverse through any kind of terrain irrespective of weather conditions. The objective is to extend the geographic sphere of influence of the soldier. The main functions in this capability area are to orient, navigate, receive and provide information on the terrain, to traverse on foot, and to carry his/her load while on the move. Sustainability is the capability of the dismounted soldier to continue his/her job for an extended period of time.

The British Defense Organization developed four generic criterion tasks to represent the key activities identified in a job analysis. Marching under load was identified as a requirement for a number of occupations and is a fundamental and common task required of all personnel (Rayson, 1997).

In the Canadian Army a series of common tasks were selected by a committee of army experts, at headquarters and in the field, as being representative of the physical requirements of the Canadian Soldier. The basic idea was that all soldiers, irrespectively of their trade, could be called upon to carry out the duties of the infantryman at some point in the battle scenario. One of the common tasks identified was a weightload march cross country in full fighting order in all weather and light conditions (Lee, 1992).

The Netherlands Army selected four common military tasks including road marching as being representative of the physically most demanding activities for the soldier in the field. Task-related physical selection standards were implemented for these tasks. Most of these tasks are also included in the physical readiness test of the Dutch Army, the so-called FIT-test. The yearly FIT-test consists of a short transfer, obstacle course, repetitive lifting/load bearing, loaded marching and loaded speed marching. The requirements on the march test are related to the specific function profile (Dijk et al., 1996, Koerhuis et al., 2004).

The scope of this chapter is to provide a review of the literature with respect to the common military task of road marching. The aim is to give evidence-based information on performance issues related to the military task of road marching. The chapter starts with a historical overview of loads carried by units in military operations (3.2) and definitions of different categories of combat loads (3.3). The energy cost (3.4) and also the physiological determinants (3.5) of loaded marching are discussed to get a better picture of limiting factors of performance on this task. Tests to monitor performance and evaluate changes in road marching performance are discussed in section 3.7. Training is one approach to increase road marching performance. Guidelines (3.8) are deduced from several training studies with military populations. Injury factors can adversely affect soldier's mobility and reduce the effectiveness of an entire unit. These factors are therefore reviewed (3.9). To support field commanders in planning and training, reference values of loaded march performance are given and the impact of loads carried on performance during the traverse and when arriving at the place of action are discussed (3.10). The chapter concludes with the finding that in modern wars the soldiers are still or even more overburdened than in past wars. Management of the soldier's load is essential to find a proper balance of firepower and mobility of the unit.

3.2 LOADS CARRIED BY UNITS IN MILITARY OPERATIONS

Lothian (1922) examined available sources to determine loads carried by the soldiers of various armies up to World War I. Until about the 18th century, troops carried loads that seldom exceeded 15 kg while they marched. Extra equipment and subsistence items where often moved by auxiliary transport including assistants, horses, carts, and camp followers. After the 18th century, auxiliary transport was de-emphasized, and more disciplined armies required troops to carry their own loads. Modern soldiers often carry a considerable amount of equipment and supplies while on the march, some of which they remove if they come into contact with hostile forces (Lothian 1922, Porter 1992).

During the Crimean War (1854 – 1856) British and French infantry loads were estimated to be about 29 and 33 kg respectively. British loads were reduced to 25 kg in 1907 but increased to 32 – 36 kg in WW1. Loading of the soldier did not stop after WW1. Holmes (1985) cited the loads shown in Table 3-1 for a variety of operations from WW1 to the Falklands Campaign.

Table 3-1: Loads Carried by Various Units and/or Carried at Various Times (from Holmes 1985)

Unit	Weight (kg)
French Poilu (WW I)	39
British Infantry on the Somme (WW I)	30
French Foreign Legion (WW I)	45
Wingate's Chindits (WW II)	31 – 41
U.S. Forces in North Africa (WW II)	60
U.S. Marines in Korea	38
U.S. in Vietnam	34
Falklands Campaign	54

Throughout history, soldiers have been expected to successfully complete missions under the most arduous of circumstances. Though technology and tactics have varied, the physical demands placed on soldiers have remained constant. Numerous historical examples support this. In 1805 during the battle of Austerlitz (Holland), Napoleon moved a corps 125 km in 50 hours and had them enter battle directly off the march. During Civil War, Major General U.S. Grant marched union troops 65 km in 27 hours to position them for the final siege of Vicksburg. In 1943 the 3rd Infantry Division marched 160 km to Palermo in 5 days.

McCaigh and Gooderson (1986) reported on the load carried by troops from the United Kingdom who were engaged in a military conflict in the South Atlantic in May and June 1982. Climate and terrain imposed heavy demands on the physical capabilities of the troops deployed. The lack of metalled roads and wheel transport dictated that almost all movement of personnel was on foot. The load carried by the individual soldier varies with their task. The lightest load, referred to as the Assault Order, is comprised of the equipment required to live and fight for a period of up to 12 hours. The addition of rations and clothing to sustain a soldier for a period of 24 hours produced the next heaviest load, referred to as the Combat Order. Finally when all personal clothing and equipment and additional rations are carried, the resulting load is known as the Marching Order. Typical weights of these loads are given in Table 3-2.

Table 3-2: Weights of Clothing and Personal Equipment Carried by a British Infantryman (kg) (Adapted from Haisman, 1988)

		Weight	Total Weight
A) Dress	Clothing, boots and helmet	7.0	7.0
B) Assault dress	Clothing, etc., as in A, weapon, ammunition, digging tool and equipment	19.4	26.4
C) Combat dress	Dress and equipment as in A and B, food and warm clothing	3.7	30.0
D) Marching order	Clothing and equipment as in A, B and C, spare clothing, rations, rucksack and sleeping bag	10.2	40.2
E) Additional equipment	There are a number of additional items which could have to be carried ranging in weight up to 16 kg		

It can be calculated that the marching order weight of 40 kg represents 51% of the nude-weight of the 50th percentile infantryman (Gooderson and Beebee, 1976), and that the 5th percentile infantryman would have been carrying 63% of this nude body-weight. Thus for an ‘average’ load weight of 50 kg the 50th percentile infantryman would have been carrying 70% of his nude body-weight and it is certain that many men were more heavily laden. Up to 20%, probably a conservative estimate, of the soldiers listed fatigue due to the weight carried or due to the lengths of the marches as a significant problem.

In addition to the basic infantry load a number of heavy and bulky items were also carried by some soldiers (Table 3-3). With the addition of support weapons, radios and extra equipment the total load carried can rise to the very high figures quoted for military operations, e.g. up to 68 kg in the Falklands operation (McCaig and Gooderson, 1986) over distances of 60 km.

Table 3-3: Examples of Weights of Additional Equipment (kg)

Additional Equipment	Weight (kg)
Machine gun	10.9
Machine gun tripod	13.6
Belt of machine gun ammunition	2.95
Anti-tank rocket launcher	16.0
2 x Anti-tank rounds	3.4
Mortar barrel	12.3
2 x Mortar bombs	8.9
Radios	1.5 – 10.8

Dublik (1987) reviewed information gathered by the Walter Reed Army Institute of Research. The members of seven infantry battalions who participated in Operation Urgent Fury in Grenada were interviewed. The general conclusion was that many soldiers were overloaded. Too few commanders enforced load discipline. A soldier stated in the interview:

> "We attacked to secure the airhead. We were like slow-moving turtles. My rucksack weighed 54 kg. I would get up and rush for 10 meter, throw myself down and couldn't get up. I'd rest for 10 or 15 minutes, struggle to get up, go 10 more meters, and collapse. After a few rushes, I was physically unable to move, and I am in great shape. Finally, after I got to the assembly area, I shucked my rucksack and was able to fight, but I was totally drained."

Not all soldiers who fought in Grenada were overloaded. Some unit commanders cut their soldiers' load to the minimum, limited contingency equipment and eliminated all non-essential items. These commanders took some risks, but they knew overloaded soldiers would reduce the unit's ability to fight and win.

Perkins (1986) reported that when elements of the 2nd and 3rd Battalions of the 325th Airborne Infantry Regiment conducted a combat air assault onto Point Salines airfield on the island of Granada in October 1983, the soldiers in these units were carrying approximately 36 kg each. This weight led to a marked decrease in their combat effectiveness.

In a 1990 article from Infantry Magazine, entitled "Load carrying ability through physical fitness training", the authors discussed recommended doctrinal carrying weights versus data collected at the Joint Readiness Training Center (JRTC). Though the Infantry school recommends a maximum of 33 kg for approach marches and 22 kg for combat actions, the authors determined that weights actually carried during simulated battle at JRTC were far greater. They found that occasionally units carried an average of 45 kg per individual and the most extreme loads were as high as 76 kg. They concluded by saying that heavy loads are the reality of the modern day battlefield and that despite the availability of transport, the need to carry loads will remain (Bahrke, 1990).

In 2003 a Soldier Load Study was conducted in Afghanistan (Dean, 2004). The study focused on the modern warrior's combat load as experienced by a U.S. Army light Infantry brigade task force fighting a low intensity conflict in the desert and mountainous regions of Afghanistan. Data was collected over a two month period in the Afghan spring of 2003 as the task force conducted continuous, hard hitting combat operations to not only deny maneuver and safe haven to enemy, but to capture or destroy Anti-Coalition Militants composed of hostile Taliban and Al Qaeda elements. A team of experienced infantrymen collected the data and conducted observations while accompanying and soldiering with the units during numerous combat operations. This study provides a rare insight into what Soldiers carry into battle.

According to the findings of the Task Force Assessment Team the dismounted infantryman was heavily loaded while conducting modern combat operations (Dean, 2004). While carrying one of the lighter combat loads in a Rifle Company, the average light Infantry Rifleman was still transporting over 43 kg of critical combat equipment in his Approach March Load when he conducted short duration dismounted operations in Afghanistan in mild to hot weather. The weights of his Approach March Load increased even further during cold weather operations and his Emergency March loads were averaging over 58 kg.

The modern dismounted infantryman continues to be over-burdened while conducting combat operations. The excessive weights on the backs of the soldiers, coupled with the harsh environments in which they operate prove detrimental to maximize Soldier performance. Despite units going to great lengths to minimize the loads that their Soldiers are carrying, the weight of the Infantry's combat load is far too great and considerably exceeds the upper envelopes established by US Army Doctrines (Dean, 2004).

Table 3-4: Average Fighting Load, Approach March Load and Emergency Approach March Load (in pounds) by Duty Position within a Light Infantry Rifle Company, while Being Active in Combat Operations in Afghanistan (Taken from Dean, 2004)

Position in Unit	Average Fighting Load	Average FL% Body Weight	Average Approach March Load	Average AML % Body Weight	Avg Emergency Approach March Load*	Average EAML % Body Weight
Rifleman	63.00	35.90%	95.67	54.72%	127.34	71.41%
M203 Grenadier	71.44	40.95%	104.88	60.25%	136.64	77.25%
Automatic Rifleman	**79.08**	44.74%	110.75	62.71%	**140.36**	79.56%
Antitank Specialist	67.66	37.57%	99.04	55.02%	130.20	79.65%
Rifle Team Leader	63.32	35.61%	93.78	52.43%	130.27	80.65%
Rifle Squad Leader	62.43	34.90%	94.98	52.59%	128.35	73.62%
Forward Observer	57.94	33.00%	91.40	52.12%	128.56	76.59%
Forward Observer RTO	60.13	35.37%	87.07	51.42%	119.13	74.94%
Weapons Squad Leader	62.66	34.02%	99.58	54.37%	132.15	69.19%
M240B Gunner	**81.38**	44.46%	113.36	62.21%	132.96	68.92%
M240B Asst Gunner	69.94	38.21%	**120.96**	66.11%	**147.82**	80.08%
M240B Ammo Bearer	68.76	36.59%	**117.06**	62.19%	**144.03**	78.46%
Rifle Platoon Sergeant	60.66	31.53%	89.96	46.35%	119.16	62.67%
Rifle Platoon Leader	62.36	34.02%	93.04	50.33%	117.62	65.44%
Platoon Medic	54.53	31.08%	91.72	51.58%	117.95	69.88%
Radio/Telephone Operator	64.98	35.60%	98.38	54.08%	no data avail	no data avail
Mortar Section Leader	58.31	30.59%	109.99	57.34%	**149.30**	90.49%
Mortar Squad Leader	60.98	37.89%	**127.24**	78.26%	**142.30**	**96.80%**
60mm Mortar Gunner	63.79	38.06%	108.76	64.22%	**143.20**	88.14%
60mm Mortar Assistant Gunner	55.34	31.93%	**122.16**	70.28%	no data avail	no data avail
60mm Mortar Ammo Bearer	53.13	30.14%	101.13	60.59%	no data avail	no data avail
Rifle Company Commo Chief	68.13	38.16%	109.69	61.67%	no data avail	no data avail
Fire Support Officer	54.11	27.32%	93.08	46.81%	no data avail	no data avail
Fire Support NCO	52.10	31.92%	90.08	55.22%	**143.30**	**98.83%**
Sapper Engineer	59.02	33.05%	95.70	53.50%	132.08	77.92%
Company Executive Officer	60.50	34.03%	93.65	52.81%	no data avail	no data avail
Company First Sergeant	62.88	33.69%	90.42	48.11%	126.00	86.30%
Company RTO	64.70	35.65%	98.09	54.27%	130.00	72.13%
RifleCompany Commander	66.10	37.08%	96.41	53.77%	111.20	70.83%
TOTAL AVERAGE	**63.08**	**35.27%**	**101.31**	**56.74%**	**131.74**	**77.82%**

3.3 COMBAT LOAD DEFINITIONS

Field Manual 21-18 (Department of the Army, 1990) provides guidance about how to conduct foot marches, including recommended maximum loads and prescribed rates of march in different conditions. Overall, the information is based on a combination of available target audience, operational need, available technology, and military judgement. It provides a published reference for determining acceptable military performance.

Combat load recommendations in the manual are based on military experience (Knapik, 1989) and on energy cost studies (from Harper et al., 1997). The combat load is the minimum mission-essential equipment required for Soldiers to fight and survive immediate combat operations, and is determined by the commander responsible for carrying out the mission. The combat load is the essential load carried by Soldiers in forward subunits or the load that accompanies Soldiers other than fighting load. Combat loads consist of three categories: Fighting Load, Approach March Load, and Emergency Approach March Load (FM 21-18).

3.3.1 Fighting Load

The fighting load includes bayonet, weapon, clothing, helmet, load bearing equipment and a reduced amount of ammunition. For hand-to-hand combat and operations requiring stealth, carrying any load is a disadvantage. Soldiers designated for any mission should carry no more than the weapons and ammunition required to achieve their tasks; loads carried by assaulting troops should be the minimum.

Unless some form of combat load handling equipment is available, cross-loading machine gun ammunition, mortar rounds, antitank weapons, and radio operators equipment causes assault loads to be more than the **limit of 21.7 kg**. This weight restricts an individual's ability to move in dynamic operations. Extremely heavy Fighting Loads must be rearranged so that the excess weight can be redistributed to supporting weapons or can be shed by assaulting troops before contact with the enemy (FM 21-18).

3.3.2 Approach March Load

The approach march load includes clothing, weapon, basic load of ammunition, Load Bearing Equipment, small assault pack, or lightly a loaded rucksack or poncho roll. On prolonged dynamic operations, the Soldier must carry enough equipment and munitions for fighting and existing until re-supply. In offensive operations, Soldiers designated as assault troops need equipment to survive during the consolidating phase, in addition to carrying munitions for the assault. A **limit of 32.7 kg** for a Soldier should be enforced (FM 21-18).

3.3.3 Emergency Approach March Loads

Circumstances could require Soldiers to carry loads **heavier than 32.7 kg** such as approach marches through terrain impassable to vehicles or where ground/air transportation resources are not available. Therefore, larger rucksacks must be carried. The Emergency Approach March Loads can be carried easily by well-conditioned Soldiers. When the mission demands that Soldiers be employed as porters, loads of up to 54.5 kg can be carried for several days over distances of 20 km a day. Although loads of up to 68 kg are feasible, the Soldier could become fatigued or even injured. If possible, contact with the enemy should be avoided since march speeds will be slow (FM 21-18).

The Infantry school added to this guidance that a soldier's weight must be taken into account. The optimal load for a soldier has been determined to be 30 percent of his body weight, and the maximum load should not exceed 45 percent of his body weight (Burba, 1986).

Based on observations during the war in Afghanistan Dean and his colleagues of the Devil Assessment Team (2004) made the recommendation that FM 21-18 be rewritten to reflect the realities of modern operations and the loads and equipment that today's Soldiers are carrying.

3.4 ENERGY COST OF MARCHING

Studies of load bearing have focused primarily on energy cost (Bobbert, 1960; Goldman and Iamprieto, 1962; Hughes and Goldman, 1970; Pandolf et al., 1976; Epstain et al., 1988; and Legg et al., 1992). Mathematical models have been developed to estimate energy expenditure during load carriage (Givoni and Goldman, 1971; Pandolf et al., 1977; and Epstein et al., 1987).

In principle, an optimum method of load carriage should induce stability, bring the centre of gravity of the load as close as possible to that of the body and make use of the larger muscle mass muscles (Legg, 1985). Locating the load as close as possible to the center of mass of the body appears to result in the lowest energy cost when loads are carried on the upper body (Soule and Goldman, 1969; and Winsmann and Goldman, 1976). Legg and Mahanty (1985) investigated five different methods of carrying a load close to the trunk. They reported that the least metabolic strain was imposed by a front/backpack method, with slightly higher oxygen costs associated with load carriage in a trunk jacket and three varieties of backpacks. Although the use of a front/backpack is physiologically associated with the lowest oxygen uptake, the method is impractical to use in many military situations. Objects on the chest may impair vision, thereby limiting manoeuvrability and restricting breathing. Consequently the backpack method of load carriage is generally favoured. Legg et al., (1992) showed that backpack load carriage is associated with lower heart rate and relative oxygen uptake (5%) than shoulder load carriage.

Studies conducted on treadmills for short periods of time show that the energy cost of backpack load carriage increases in a systematic manner with increases in:

Body Mass (Falls and Humphrey, 1976; Goldman and Iampietro, 1962; and Passmore and Durnin, 1955);

Load Mass (Borghols 1978; Goldman and Iamprieto, 1962; and Soule et al., 1978);

Velocity (Goldman and Iamprieto, 1962; Soule et al., 1978; and Workman and Armstrong, 1963);

Grade (Borghols, 1978; Goldman and Iamprieto, 1962; Pandolf et al., 1977); and

Type of Terrain (Haisman and Goldman, 1974; Pandolf et al., 1976; Soule and Goldman, 1972; and Patton et al., 1991).

Givoni and Goldman (1971) used these relationships to develop an equation for predicting energy costs of locomotion with backpacks. Pandolf et al., (1977) revised this equation and included a factor for energy cost of standing with loads. This formula was developed to include standing and walking at all speeds up to running 8.6 km/h, at grades from 0 to 25% with loads from 0 to 70 kg and a variety of terrains. Since the Pandolf equation only considers speeds up to 8.6 km/hour, Epstein et al., (1987) expanded the equation to include a term for running (up to 11.5 km/hour). The Pandolf equation has been independently validated using a range of loads and body masses (Duggan and Haisman, 1992).

Table 3-5: The Equations to Predict the Short Term Energy Cost of Locomotion with Backpack Loads

Equation Givoni and Goldman 1971 $M_w = T \bullet (W + L) \bullet [\ 2.3 + 0.32 \bullet (V - 2.5)^{1.65} + G \bullet (0.2 + 0.07 \bullet (V - 2.5))]$
Equation Pandolf et al., 1977 $M_w = 1.5 \bullet W + 2.0 \bullet (W + L) \bullet (L / W)^2 + T \bullet (W + L) \bullet (1.5 \bullet V^2 + 0.35 \bullet V \bullet G)$
Equation Epstein et al., 1987 $M_r = M_w - 0.5 \bullet (1\text{-}001 \bullet L) \bullet (M_w = -15 \bullet L - 850)$

Symbols: M_w = metabolic cost of walking (watts); M_r = metabolic cost of running (watts); W = body mass (kg); L = load mass (kg); T = terrain factor; V = velocity or walk rate (m/s); G = slope or grade (%)

Terrain factors: 1.0 = black topping road; 1.1 = dirt road; 1.2 = light brush; 1.5 = heavy brush; 1.8 = swampy bog; 2.1 = loose sand; 2.5 = soft snow 15 cm; 3.3 = soft snow 25 cm; 4.1 = soft snow 35 cm

Energy expenditure is an important variable in military field situations. It provides commanders with valuable information about the physical strain of a certain loaded traverse. Choosing the right combination of load carried and speed, given certain characteristics of terrain and distance, dictates soldier's mobility and the capacity of the soldier to continue their job for an extended period of time. As an example, energy expenditure for certain combinations of speed, load carried and terrain factors are shown in Figure 3-1. Speed of traverse, more than load carried, is a very important factor determining the actual energy expenditure.

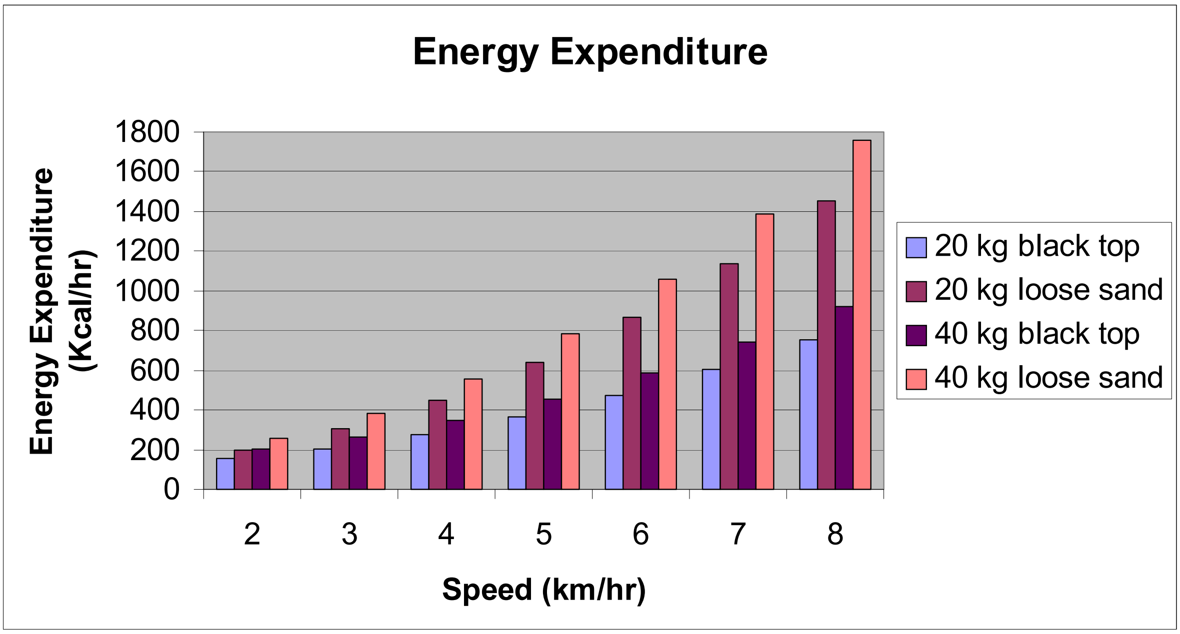

Figure 3-1: Effect of Speed, Terrain and Load Carried on Energy Expenditure. (Pandolf 1977)

A limitation of the Pandolf equation may be the fact that it does not account for possible changes in energy cost over time. In studies used to develop the equation, energy costs was examined for short periods, usually less than 30 minutes. Research gives conflicting results about the effect of duration of work on energy expenditure. Epstein et. (1988) and Patton et al., (1991) showed that the energy cost of prolonged (>2 hours) load carriage at a constant speed increased over time at higher loads and/or speeds. Epstein et al., (1988) found an 8.8% increase in VO_2 over 2 hours while carrying 40 kg at a speed of 4.5 km/hour and a 5% grade. They concluded that an exercise intensity greater than 50% of VO_2max was required before an increase in VO_2 was found. Patton et al., (1991) noticed an increased VO_2 even at initial intensities of about 30% of VO_2max. They concluded that applying the prediction model which estimates energy expenditure from short-term load carriage efforts to prolonged load carriage can result in significant (10 – 16%) underestimation of the actual energy cost. A factor which may be of particular importance is the reduction in mechanical efficiency due to altered locomotion biomechanics as the subjects adjusts to the weight of the pack (Rowell, 1971; and Martin and Nelson, 1986). However these results were not confirmed in a more recent study of Sagiv et al., (1994). Differences in aerobic fitness of subjects and the system used to carry the load may explain the differences found in these studies. Whether or not energy cost increases over time is an important issue because increased energy cost is related to earlier fatigue and possible decrements in military performance of the individual soldier.

Studies have illustrated that subjects adjust their kinematics in response to a heavy backpack load. The adjustments include a shortened stride length (Martin and Nelson, 1985), greater knee flexion at heel-strike, and a straighter knee at mid stance (Han at al., 1993). Givoni and Goldman (1971) suggested that as the product of speed (km/h) and load (kg) exceeds the numerical value of 100, there is an inefficiency, which increases energy cost. Martin and Nelson (1986) in studying the walking patterns of men and women during load carriage, found a decrease in stride length and swing rate while stride rate increased with increasing load. In addition, there was an increased forward inclination of the trunk at their heaviest load (36 kg). Stride length is one factor known to affect VO_2 during running where variations from an optimum length result in increasing greater energy demands (Daniels, 1985). Quesada et al., (2000) studied the biomechanical and metabolic effects of varying backpack loading on marching. Each 15% body weight load increment resulted in a proportional metabolic cost increase of approximately 5 to 6%.

The energy expenditure equations can provide valuable information as to the physical severity of load carriage tasks and the potential for ensuing fatigue. For field studies it is possible to estimate absolute energy rate, total energy expenditure and relative exercise intensity during loaded marching. To estimate energy expenditure rate the standard equation of Pandolf et al., (1977) can be used. Total energy expenditure can be estimated by multiplying the estimated energy expenditure rate by march time. Estimating relative exercise intensity requires several steps (Knapik et al., 1993):

1) Estimated energy expenditure rate (Pandolf et al., 1977) is converted to liters O_2/min under the assumption that about 5 kilocalories is the energy equivalent of 1 liter O_2;

2) VO_2max (l/min) of each soldier is estimated or measured using lab test or field tests (ACSM, 2000); and

3) Energy expenditure rate (liters O_2/min) is divided by the VO_2max (liters O_2/min) and multiplied by 100% to obtain the estimated relative exercise intensity.

Rayson et al., (1995) argued that it is essential to measure the maximum or peak oxygen uptake during the actual task loaded marching and not maximum oxygen uptake derived from treadmill running tests in the laboratory or predicted maximum oxygen uptake from field running tests. The VO_2max measured during loaded marching is significantly less than that measured during running (Rayson et al., 1995). This is in accordance with other studies that have shown VO_2max to vary with the kind of exercise performed and the muscle used (Asmussen and Hemmingsen, 1958; Hermansen et al., 1970; Petrofsky and Lind, 1978;

and Smith et al., 1996). An important aspect of this finding relates to the description of intensity of submaximal efforts. During an analysis of the physical demand of a task, the intensity of submaximal efforts should be expressed as a function of the maximal power (VO_2max) of the task being examined and not as a function of another kind of work, i.e. VO_2max of running. For example if the VO_2 of a loaded march is expressed as being 50% VO_2max for running, one should assume the individual is marching at a sustainable rate. In reality, however, the individual is working at 63% VO_2peak for loaded marching, a value which may exceed the maximum sustainable work rate (Rayson et al., 1995). Using the VO_2max for running thus significantly underestimates the work effort.

The same idea of underestimating the intensity of work may be applied to using heart rate to estimate the work effort. Knapik et al., (1993) showed that when soldiers were asked to perform a 20-km march with a load of 15 kg as quickly as possible, the mean peak heart rate was 155, which is well below the predicted maximal heart rate of 191 for this group of soldiers. Nevertheless, the soldiers were working at or near maximal levels of loaded marching. A comparison of heart rate for loaded marching and running greatly underestimates the actual intensity of the work in loaded marching.

3.5 PHYSIOLOGICAL DETERMINANTS OF MARCH PERFORMANCE

There are many factors that influence the ability of a soldier to carry load and road march. These include mass of load, speed of march, type of terrain, distribution of the load (Datta and Ramanathan, 1971; and Kinoshita 1985), volume of the load (Holewijn and Lotens, 1992) and the medical condition of the soldier (Knapik et al., 1992). Some of these factors have been studied, but usually in relation to the energy cost of the task and not in relation to the physiological profile of soldiers that determines load-carriage performance.

A typical research approach to relate task performance to the physiological profile is to administer subjects a series of physiological tests that measure muscle strength, anaerobic capacity, aerobic capacity and body composition. The subjects are also administered to a load carriage test. Task performance on the load carriage test is then correlated with the various physiological measures.

Several authors have shown a negative relationship between fatness and march performance (Dziados, 1987; and Rayson et. al., 1995), though there is little consensus to the extent of impact of body fat. Excess body fat is dead weight in the performance of work and degrades the performance of physical tasks involving movement of the body and an external load. An interesting question is whether carrying weights has the same effect on energy expenditure as passive body weight (fat). Goldman and Iamprietro (1962) studied subjects walking on a treadmill at speeds of 2.4 – 6.4 km/hour, grades of 3 – 9% and carrying loads of 0 – 30 kg. They concluded that for fairly fit individuals walking at a given speed and grade the energy cost/kg is independent of the extra weight carried. Up to limits of 30% of body weight the energy cost/kg is found to be the same for weight load and live weight (Datta and Ramanathan, 1971). Borghols et al., (1978) also reached the conclusion from their experiments (speed 5 km/hr, carrying loads 0 – 30 kg), that there is no difference in energy cost/kg whether the weight is carried as an external weight or as live weight. They suggest that a decrease in body fat mass may permit subjects to increase their work load or to do the same work with less exertion. Within the range of 0 – 30 kg each kilogram carried load accounts for an average increase in oxygen uptake of 0.335 $ml \bullet kg^{-1} \bullet min^{-1}$ and a heart rate of 1.1 beats per minute.

Higher lean body mass is associated with faster load carriage. Lean body mass is strongly related to strength and this helps to support and move the load carried. The correlations are stronger for lean body mass than for percent body fat. Table 3-6 shows correlations of load carriage performance with lean body mass and percent body fat.

Table 3-6: Correlations of Load Carriage Performance with Lean Body Mass and Percent Body Fat (Male Subjects)

	Distance	Load	Lean Body Mass	Percent Body Fat
Dziados et al., (1987)	16 km	18 kg	– 0.30	0.15
Mello et al., (1988)	2 km	46 kg	– 0.54	0.00
	4 km	46 kg	– 0.39	0.38
	8 km	46 kg	– 0.45	0.48
	12 km	46 kg	– 0.55	0.29
Knapik et al., (1990)	20 km	46 kg	– 0.26	0.05

Studies by Rayson et. al. (1993 and 1995) on female soldiers and by Frykman and Harman (1995) on male soldiers, identified height as a fair predictor of the ability to march with a load. In a study by van Dijk et al., (1996) a positive correlation of 0.46 was found between height and the performance on a marching test with load carried up to 62.5 kg and a speed of 6 – 7 km/hr.

Load carriage ability is not well predicted by unloaded running. Knapik (1990) found a correlation of 0.16 between 3.2-km run times and 20-km loaded march times. The reason is that a slight body build is well-adapted to unloaded running, but it is not adapted to load carriage, particularly as loads become heavy. Larger people tend to have a greater lean body mass which helps to support and move the load carried (Teves et al., 1985; Harman et al., 1988; and Myers et al., 1983). Bilzon et al., (2001) tested the hypothesis that simple field tests of aerobic fitness are not predictors of load-carrying performance and personnel with greater body mass are more able to perform occupational relevant load-carrying tasks. Their data showed that there is no relationship ($r = 0.12$) between relative VO_2max ($ml•kg^{-1}•min^{-1}$), determined with an unloaded running test, and exercise tolerance time (load 18 kg speed 9.5 km/h) during load-carrying tasks. Exercise tolerance time was moderately strong related to body mass ($r = 0.69$, $p<0.05$) and lean body mass ($r = 0.71$, $p<0.05$).

Several studies have investigated the relationships between performance on loaded march tasks and various physical tests. The test batteries were reasonable comprehensive in these studies, encompassing all the aspects of physical capability. Measurements of anthropometry and body composition, strength, endurance and aerobic power provided the best predictors of marching performance (see Table 3-7).

Table 3-7: Summary of Studies Reporting Relationships between Performance on Loaded March and Physical Tests

March Task	Author/Subjects	Physical Tests – Best Predictors
Time for 16 km, 18-kg load	Dziados et al., 1988 49 males	Fat, muscle mass, isok knee flex end, isok knee ext end, isok knee flex strength, isok knee ext strength, VO_2max
Time for 12 km, 46-kg load	Mello et al., 1988 28 males	Fat, muscle mass, ILM183, isok knee flex end, isok knee ext end, isok knee flex strength, isok knee ext strength, VO_2max
Time for 20 km, 46-kg load	Knapik et al., 1990 96 males	Height, mass, fat, ffm, isom knee ext, isom hand grip, isom upper torso, isom trunk flex, isom knee flex, isom ankle plantar flex, isok knee ext, isok knee flex, arm Wingate, leg Wingate, VO_2max
Max load at 6.4 km/hr on treadmill	Rayson et al., 1993 and 1995 18 females	Height, mass, fat, ffm, age, isom trunk flex, isok knee ext, isok hip ext, isok plantar flex, isok shoulder ext, isok shoulder adductors, knee flex.ext endurance, VO_2max
Time for 3 km, 34-kg load	Frykman and Harman, 1995 13 males	Height, mass, fat, ffm, shoulder diameter, squat endurance, VO_2max
Incremental march protocol load 25 – 62.5 kg, speed 6 – 7 km/hr	Dijk, 1996 160 males	Height, ffm, shoulder height, skelet weight, isom lifting force 140 cm and 90 cm, isok shoulder press, isok squat, isom leg press, VO_2max cycling, VO_2max arm cranking, Cooperscore
Incremental march protocol load 25 – 62.5 kg, speed 6 – 7 km/hr	Dijk 1996 80 females	Ffm, mass, isok flex trunk, isok squat, isok bench press, isok shoulder press, isom lifting force 90 cm, isom leg press, isom arm ext, isom trunk ext, VO_2max cycling, VO_2max arm cranking,
Incremental march protocol 7.5 kg / 4 min above body weight 3 km/hr 5% grade	Koerhuis et al., 2005	Height, body weight, ffm, isom leg extension, isom trunk flex, isom trunk ext, dyn squat, dyn shoulder press

Legend:

ext = extension	isok = isokinetic
ffm = fat free mass	isom = isometric
flex = flexion	UP = upright pull
ILM = incremental lift machine	

Amongst the strength tests, several isometric and isokinetic variables were among the best predictors. Isometric upper torso and trunk flexion strength (Knapik et al., 1990; and van Dijk, 1996), isokinetic upper torso strength (van Dijk, 1996), isokinetic knee flexion (Dziados et al., 1987; and Mello et al., 1988), knee extension strength (Mello et al., 1988) and plantar flexion (Rayson et al., 1993 and 1995) are correlated to load march performance. Core stability, strength in the core region of the body, and strength in the extension chain seems to be important for loaded marching.

Measurements or estimates of aerobic fitness were amongst the best predictors in a number of studies. The highest correlation values were recorded between marching performance and absolute VO_2max

(Frykman and Harman 1995) with a value of 0.84 ($p<0.05$). However the distance of this march task was only 3 km. In other studies, moderate correlation values of between 0.4 and 0.6 were observed between march time and aerobic fitness.

Several studies attempted to produce multiple regression models to predict marching performance. The model of Rayson et al., (1995) for maximum tolerable load included VO_2max, ankle plantar flexion, age and body fat, producing an r^2 value of 0.71. Dijk et al., (1996) used a progressive loaded march test. For men, body height, isometric trunk extension strength, 12-min run score, and isokinetic squat strength were included in their multiple regression model, with an explained variance of 56%. In women, static lift force at 40 cm, number of press-ups in two minutes, lean body mass, number of sit-ups, and bench press isokinetic strength are predictive variables in the multiple regression equation with an explained variance of 66%.

3.6 TESTING OF MARCH PERFORMANCE

Testing the physical fitness and readiness of soldiers and units is essential for military practice and training. The most important reasons are shortly discussed in the following list (Gore, 2000).

1) **Identify Weakness**. The main purpose of testing is to establish where a soldier's strengths and weaknesses lie. This involves identifying the major underlying fitness components required for performance of the task and then conducting tests that measure these components. A training program that is geared towards the development of the individual soldier and/or unit can then be prescribed.
2) **Monitor Progress**. By repeating appropriate tests at regular intervals, the unit commander can obtain a guide to the effectiveness of the prescribed training program. A "one-shot" testing experience provides very little benefit either for the soldier or the commander and is strongly discouraged.
3) **Provide Feedback**. The feedback of a specific test score often provides incentive for a soldier and unit to improve in a particular area, as he or she knows that the test will be repeated at a later date.
4) **Educate Commanders and Soldiers**. A testing program can provide commanders and soldiers with a better understanding of the task and the attributes that are required to be effective. This facilitates systematic planning of soldier development programs.

O'Connor et al., (1994) argued that one of the most difficult aspects of physical fitness training at unit level is the planning of the program. He recommended a 6-step method for use in developing and planning unit physical fitness programs. It is oriented towards full-time operational battalion and company level units.

Step one is to define the training objectives based on mission requirements. A realistic goal for road marching with loads in light infantry units is, in their opinion, to work up to carrying 45 percent of body weight for a distance of 16 km in four hours. At the end of the march, the soldiers should be able to perform critical soldier skills (O'Connor et al., 1990). Step 2 and 5 is to analyse and evaluate unit and individual fitness and task performance. Before training can be effectively planned, the current level of fitness for the unit as a whole and for individual soldiers must be known. This will identify the areas where training is needed. Evaluation and observation of soldier performance of mission-related tasks will provide information about unit and individual fitness. It is appropriate to conduct mission-specific events, such as a road march for a set distance with a prescribed load to obtain a complete picture of unit physical conditioning as it relates to military task performance. Reassessment of unit and individual fitness should be performed for determining the effectiveness of the physical training program. Testing of physically demanding mission task performance is important to evaluate the effectiveness of the physical training program.

NATO RSG-4 (1986) defined physical fitness as the capacity to perform physical activities. It consists of three components or types of fitness based on the nature of the task and the predominant source of energy for that activity. These three fitness components are muscular strength, muscular endurance, and aerobic fitness.

The military uses two approaches to monitor and evaluate the performance and physical fitness of soldiers and units. One approach is to test on a regular basis the physical capability of certain fitness components, such as sit-ups, push-ups for the muscular endurance component, or the 12-min run and 2-mile run for the aerobic fitness component. For a complete overview of military tests used by various NATO nations, the reader is referred to the review in the final report and resource manual on military physical training (von Restorff, 1994).

The second approach is to develop tests, which actually simulate the task event. Several NATO nations have developed task tests to monitor task performance and evaluate training programs. Knapik et al., (2004) recommended a number of criteria in selecting appropriate tests for use by the Defence organisation. The tests should be valid, reliable, non-discriminatory in nature, associated with occupational indicators like job performance, injury risks and attrition/job failure risks and administratively practical.

Several road marching tests are currently in use by NATO-countries. Basically three types of tests are used:

1) Loaded marching time trials with loads varying between 5 to 68 kg over distances of 5 to 20 km. The loads are chosen to approximate the different types of combat loads – Fighting Load, Approach March Load and Emergency Approach March Load. Table 3-8 outlines field tests for loaded marching and performance data.
2) Incremental loaded road marching test. A good example is the test developed in the Netherlands in which the intensity was increased by manipulation of the load and speed. Loads of 25 kg, 38 kg, and 50 kg were carried in sequence at a speed of 6 km/h; a 63 kg load was carried at 6, 6.5 and 7 km/h. The performance measure was distance covered until the soldier was unable to maintain the pace (Dijk, 1996).
3) A submaximal test in which a pass/failure scores based on operational task or job specialities are imposed (Rayson, 1997; Lee, 1992; and Koerhuis et al., 2004).

The important factors for road marching are speed of traverse, load carried, body mass and terrain. In military training and operational settings the loaded-march tasks vary greatly. Depending on the task variables a different mix in fitness components – muscular strength, muscular endurance and aerobic fitness – is stressed. This is related to the involvement of the different energy producing systems. In this area no systematic research has been conducted. One could expect that patrolling and ruck-sack marching over longer distances or at higher speeds will predominantly stresses the aerobic component of fitness. Carrying heavier loads during road marching will also stress the muscular endurance component. In testing soldiers the specific demands of the mission – in regards to load carried, distances, terrain, speed of movement – should be kept in mind. The physical requirements of the tests have to be valid for the physical task in the field. In addition a loaded road marching test needs to be realistic, reliable, challenging and standardised.

Table 3-8: Field Tests for Loaded Marching and Performance Data

Study	Loaded March Test Time-trial	Performance	Subjects	Characteristics
Rasch et al., 1964	4.8 km – 14.5 kg track sand and clay, rolling terrain	35.1 ± 2.6	Male N = 14	4.8 km run 29.6 min ± 1.5
Dziados et al., 1987	16 km – 18 kg asphalt road, one steep hill, rolling hills 3 km	145 min ± 19	Male N = 49	Height 176 cm ± 6.7 Weight 73.5 kg ± 9.8 BF 15.5 kg ± 6.3
Knapik et al., 1996	5 km – 19 kg paved roads no grade	44.7 min ± 2.8	Female N = 21	Height 167 cm ± 7.9 Weight 67.0 kg ± 8.9 BF 27.6 kg ± 7.3 3.2 km run 20.3 min ± 1.7
Harper et al., 1997	10 km – 18 kg 10 km – 27 kg 10 km – 36 kg road not specified	89.5 min ± 10.6 92.2 min ± 10.2 108.3 min ± 13.8	Male N = 19	Height 172 cm ± 6.8 Weight 71.9 kg ± 12.3 BF 13.5 kg ± 4.4 3.2 km run 15.6 min ± 1.9
Harper et al., 1997	0 km – 18 kg 10 km – 27 kg 10 km – 36 kg	111.3 min ± 11.4 116.5 min ± 16.5 138.3 min ± 20.4	Female N = 15	Height 163 cm ± 4.8 Weight 62.2 kg ± 5.4 BF 25.9 kg ± 6.5 3.2 km run 19.2 min ± 1.7
Knapik et al., 1993	20 km – 34 kg 20 km – 48 kg 20 km – 61 kg dirt (8 km) and paved roads (12 km, no grade	171 min ± 31 216 min ± 34 253 min ± 26	Male N = 15	Height 176 cm ± 5.5 Weight 87.8 kg ± 10.3 BF 21.0 kg ± 3.6 3.2 km run 13.7 min ± 1.2
Rayson, 1997	12.8 km – 15 kg 12.8 km – 20 kg 12.8 km – 25 kg flat bitumen	98 min ± 12.4 102 min ± 11.1 103 min ± 10.6	Male N = 304	Height 176 cm ± 6.3 Weight 87.8 kg ± 10.3 VO_2max 3.6 l/min ± 0.46
Rayson, 1997	12.8 km – 15 kg 12.8 km – 20 kg flat bitumen	120 min ± 15.6 126 min ± 11.0	Female N = 75	Height 164 cm ± 6.7 Weight 62.6 kg ± 7.9 VO_2max 2.4 l/min ± 0.33
Pandorf et al., 2001	3.2 km – 14 kg 3.2 km – 27 kg 3.2 km – 41 kg paved, four small hills	25.7 min ± 2.6 30.7 min ± 3.7 36.9 min ± 4.8	Female N = 12	Height 166 cm ± 6.5 Weight 61.3 kg ± 6.5 BF 25.7 kg ± 3.2 VO_2max 3.0 l/min ± 0.5 3.2 km run 17.0 ± 1.1

3.7 TRAINING FOR MARCHING

Loaded marching is an essential task in military operations. Nevertheless, only a limited number of studies have been executed to investigate the improvement in load carriage attributable to physical training (Table 3-10).

Kraemer et al., (1987) evaluated the effect of resistance training and aerobic fitness training on a maximal effort 3.2 km load bearing task with a load of 45 kg. Soldiers were randomly assigned to one of four training groups: group 1 upper and lower body resistance training and high intensity endurance training; group 2 upper body resistance training and high intensity endurance training; group 3 upper and lower body resistance training only; group 4 high intensity endurance training only. Training took place 4 times per week for 12 weeks.

It was found that when either upper- or lower-body resistance training was combined with high intensity endurance training, load carriage performance time significantly improved. However, no improvements were evident when subjects participated in either resistance training alone or high intensity endurance training alone (Table 3-9). These results demonstrate that a combination of resistance training and aerobic fitness training is necessary to improve performance on a load bearing task of a short duration and high intensity in nature. Programs that only focus on aerobic fitness or muscular strength were not effective.

Table 3-9: Changes in Load Carriage Performance as a Function of Type of Training

Training Group	Pre-training	Post-training	Change (%)
Group 1 Total body resistance + aerobic	25:18	21:45	16
Group 2 Upper body resistance + aerobic	28:37	25:32	12
Group 3 Total body resistance only	29:27	28:12	4
Group 4 Aerobic only	30:32	30:31	0

Table 3-10: Improvements in Loaded March Performance by Training

Author	Population	Testing	Training Program	% Improvements
Kraemer 1987	Male soldiers N = 35	Time trial 3.2 km, 44.7-kg load	12 weeks 1) Aerobic 2) Aerobic – Strength 3) Strength	 0 14 4
Knapik et al., 1996	Female soldiers N = 21	Time trial 5 km, 19-kg load	14 weeks Resistance + Running	4
Harman et al., 1997	Female soldiers	Time trial 3.2 km, 34.1-kg load	24 weeks Resistance, running, backpack hiking	33
Kraemer et al., 2001	Female soldiers N = 93	Time trial 3.2 km, 34.1-kg load	6 months 1) Total body resistance 2) Upper body resistance 3) Field 4) Aerobic	 8 10 8 NS
Visser et al., 2005	Male soldiers N = 76	Incremental march test load 25 to 65 kg speed 6 – 7 km/h	8 weeks Strength and Aerobic 1) Load 20 – 32% BW, 8 – 19 km per session, weekly 2) Load 20 – 32% BW, 8 – 19 km per session, bi-weekly 3) Load 45 – 67% BW, 4 – 6 km per session, weekly 4) Load 45 – 67% BW, 4 – 6 km per session, biweekly	7 6 18 9

Kraemer et al., (2001) examined the effects of 6 months resistance training on strength, power, and military occupational task performance in women. Untrained women, mean age 23 years, were placed in total- or upper-body resistance training, field, or aerobic training groups. Two periodized resistance training programs (with supplemental aerobic training) emphasised explosive exercise movements (3 – 8 RM training loads), whereas the other two emphasised slower exercise movements using 8 – 12 RM loads. The field group performed plyometrics and partner exercises.

Women who participated in the total body and upper body resistance training program, as well as field training, showed significant improvement in 3.2-km run times with a 34.1-kg load. On average the improvements were 17%, or 350 seconds. Aerobic training alone did not improve 3.2-km loaded-run performance times, indicating that a combination of strength/power and aerobic endurance was vital for improvement in this type of task. It is possible that enhanced load carriage may be due to improved postural support from stronger upper-body musculature, which improves the mechanics of loaded locomotion. Their data show that performance can also be enhanced in young untrained women without such direct practice. This may help in potentially reducing the incidence of overuse injuries related to task specific training.

Knapik et al., (1990) studied the effectiveness of different training programs to improve performance on a 20-km road march while carrying a total load of 46 kg. The training programs were similar, consisting of endurance training, resistance training, interval training and callisthenic exercises, except for the amount of loaded road march training. Four groups were formed: no road marching, road marching once, twice, and four times a month. Road marching was progressive with respect to the load (0 – 34 kg), and distance (8 – 16 km). There was no change from pre- to post-training in load carriage performance for any of the groups. This finding was attributed by the authors to longer rest breaks and warmer ambient temperature during post-training test period. However groups that performed either 2 or 4 loaded road marches per month during the training period covered the 20-km course significantly faster (43 min or 12%), than groups that trained either none or 1 loaded road march per month.

The criterion road march task was extremely strenuous, according to the NCOs. They commented that it was the most strenuous road march they had ever performed. On average the heart rate during the road march was 135 beats/min or 68% heart rate max which correspondents to 53% of maximal oxygen uptake (Londeree, 1976). The results indicate that road marching twice a month with progressively increasing loads is as beneficial as marching 4 times a month. Soldiers in the 4 marches a month group complained of the frequency of the marches as it interfered with other training requirements. The authors suggest that when planning training schedules units should regard 2 times per month as a minimum frequency for road march training. The results also support the specificity of training. Despite the fact that all groups performed a physical training program designed to improve the major components of physical fitness, only groups training at least twice a month were faster on the post-training march.

Knapik and Gerber (1996) examined the effect of a combined resistance and aerobic training program on manual material handling tasks and on a 5 km, 19 kg, load carriage march of female soldiers. They trained for 14 weeks, performing progressive resistance training 3 days per week and running with interval training 2 days per week. They improved their maximal effort road march time over 5-km distance, carrying a 19-kg load mass by 4%.

Harman et al., (1997) studied the effect of a 24-week physical training program that included weightlifting, running, backpack hiking and special drills on a 3.2-km run/walk performance among women carrying a 34.1-kg load, and found a 33% improvement in speed.

Loaded marching performance is an important task activity of military personnel. The optimum training to improve marching performance appears to be a combination of resistance training, endurance training and task repetition (Kraemer, 1987; and Kraemer, 2001). However, for each soldier, the specific area of relative deficiency may be in either muscle strength or aerobic endurance. Perhaps a more effective approach to improve loaded march performance would be to prescribe training programs focused on either resistance or endurance training, based on each individual's pre training performance.

Williams et al. (2004) explored the possibility of training diagnosis for a 3.2-km loaded march with a 25-kg load. Fifty men trained for 10 weeks using either:

i) Running, marching, and endurance-based circuit training; or

ii) Running, marching, and resistance training.

The march was performed before and after training, and other measurements related to loaded marching were conducted before training only. Each group was ranked by improvement in the loaded march, and divided into significantly different subgroups of 'good' and 'poor' responders (improvements approximately 20% vs. 10%). For the circuit-training group, stronger subjects with lower endurance responded better to the program. The resistance-training group tended to show the opposite effect. Recruits with a better endurance and lower strength capacity tended to respond better to the resistance-training program.

Traditionally, training for loaded marching was mainly comprised of long and extensive walks. This "tradition" is time-consuming and prone to injuries (Koplan et al., 1982; and Marti et al., 1988). However, if strength appears to be the limiting factor, short and intensive road march training might be beneficial and worth looking at.

Visser et al., (2005) examined training effects of a traditional method of loaded march training (long distance and moderate load) compared to a method based on short multiple bouts of marching (short distance and heavy load). In addition, the effect of training frequency (twice or four times a month) was studied. Fifty male and female officers of the Royal Military Academy participated in an eight-week training study. Before and after training they measured: anthropometry (body weight, height, percentage body fat), strength, aerobic endurance (shuttle-run test), a 3.2-kilometres speed march, and an incremental loaded march test. The speed march protocol was based on a 2 minutes of running and 1 minute of walking interval, carrying an external load of 17.5 kilogram. The loaded march test started at a load of 25 kg for men and 15 kg for females and was increased every 1000 meters (10 minutes) by 12.5 kg up to a total weight of 62.5 kg. Marching speed commenced at 6 km/hr, and was consecutively increased by 0.5 km/h every 1000 meters until exhaustion. All participants followed a general training program that included two training sessions per week consisting of both aerobic endurance and resistance training. In addition four marching groups were formed.

For groups 1 and 2 (duration program) march training load increased from 20 to 32% of the individual bodyweight for women and 25 to 40% for men. The training march distance increased from 8.3 km (90 min) to 16.5 km (180 min) at a speed of 5.5 km/h. For groups 3 and 4 (intensity program) training load increased from 35 to 55% of the individual bodyweight for women and 45 to 67.5% for men. The march distance increased from 4.1 km (3 bouts of 15 min) to 5.5 km (4 bouts of 15 min). Training groups 1 and 3 marched every week and groups 2 and 4 marched once every two weeks. The general physical training was effective. Overall strength and aerobic endurance increased significantly (20% and 7% respectively) for the total population. Time to complete a 3.2 km speed march with a total load of about 17.5 kg, decreased (5%) significantly. Increments in performance on the incremental loaded march test were related to the training program. The intensity programs were twice as effective as the duration programs (13.5 vs. 6.5%). March training once a week was more effective than bi-weekly march training (12.6% vs. 7.4%). Total time needed for the march training was very different between the training programs. Group 1 (intensity program weekly) trained 7 hours, group 2 (intensity program bi-weekly) 3.5 hours, group 3 (duration program weekly) 18 hours and group 4 (duration program bi-weekly) 9 hours.

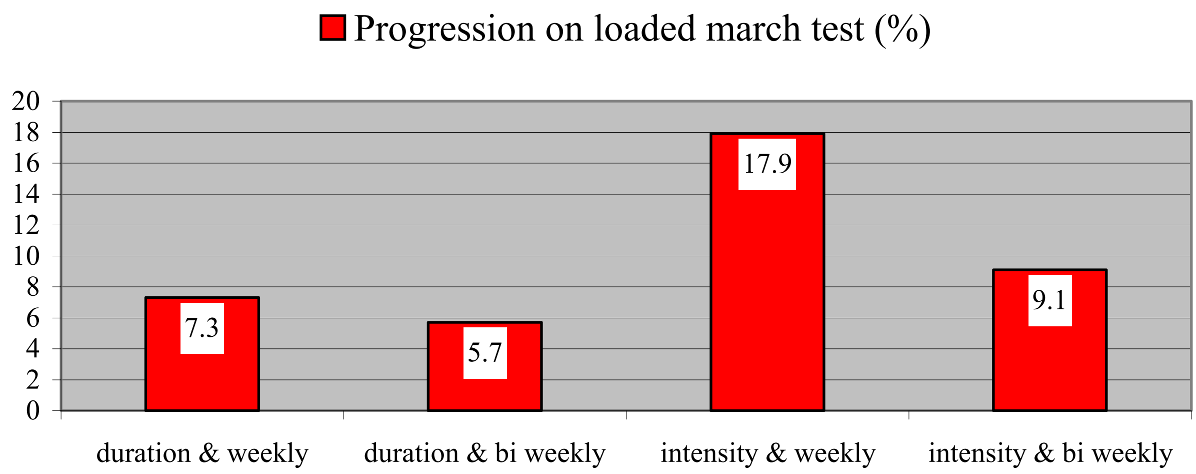

Figure 3-2: Improvements in Loaded March Performance as a Function of Type of Physical Training. (Visser et al., 2005)

It was concluded that an eight-week training program increased strength, aerobic endurance, speed march performance and loaded march performance of a moderate to well-trained group of officers at the Royal Military Academy. Based on effectiveness and training time, a 10-day training cycle for march training was advised.

Loaded march performance (load carriage) is an important duty of military personnel, and the optimal training to improve performance appears to be a combination of resistance training and lower body endurance training (Kraemer, 1987 and 2001). Both aerobic endurance and resistance training are forms of general training. Some task specific training by loaded road marching is probably needed to meet specificity requirements (McCafferty, 1977), but excessive marching may be costly in terms of training time and increased risk of injuries (Koplan et al., 1982; and Marti et al., 1988). The study of Visser et al., (2005) indicates that depending on the operational requirements, short but intensive training is a very cost effective training approach and the benefits in terms of progress in road marching performance with heavy weights are substantial. In the Netherlands a 10-day cycle for road march training has been implemented.

3.8 INJURIES RELATED TO MARCHING

Medical problems and injuries associated with load carriage can adversely affect an individual's mobility, and in military operations, reduce the effectiveness of an entire unit. Overuse injuries associated with strenuous marching are primary medical problems for recruits during basic training and for soldiers in infantry units. Ross (1993) review overuse injuries during basic military training and found that, among recruits participating in 8 weeks of basic training, the reported incidence of marching-related injuries is as high as 60 – 70%.

Knapik et al., (1992) found that 24% of infantry soldiers who participated in one road march while carrying heavy external loads suffered an overuse injury. Marching overuse injuries can impair function and subsequently impede performance in strenuous activities.

From epidemiological reports, common types of injuries include: blisters, plantar fasciitis, achilles tendonitis, shin splints, stress fractures (most commonly in the tibia and metatarsals), anterior compartment syndrome, chondromalacia patellae and low-back strain. Factors commonly implicated in marching injuries include load, excessive fatigue, terrain, footwear and amount of hiking (Volpin et al., 1989; Knapik et al., 1992; and Ross, 1993).

Vogel et al., (1994) reviewed injuries related to military physical training. Military physical training, including road marching, incurs a risk for musculoskeletal injuries. Factors or conditions, which place military personnel at risk for musculoskeletal injuries during physical training can be divided into two categories: extrinsic and intrinsic, i.e. those outside the individual and those within the individual. Jones (1983) produced a list of most common identified classes of risk factors. Most of these factors are also related to the incidence and severity of loaded march related injuries.

Extrinsic

- Training program parameters;
- Footwear; and
- Training surface.

Intrinsic

- Initial low level of fitness/inactivity;
- Anatomical anomalies;
- Inappropriate flexibility;
- Excess body fat;
- Gender and age;
- Health factors; and
- Prior injury history.

Knapik et al., (1996) reviewed the literature on prolonged load carriage and medical aspects. They noticed some common patterns of injuries with the majority of the injuries involving either the lower extremities or the back. The major load carriage related injuries are foot blisters, metatarsalgia, stress fractures, knee pain, low-back injuries, rucksack palsy, local discomfort and fatigue during load carriage. Table 3-11 gives an overview of the injuries and potential preventive measures.

Table 3-11: Common Injuries Associated with Load Carriage, Risk Factors and Preventive Measure (Adapted from Knapik et al., 1996 and 2004)

Injury	Risk Factor	Preventive Measure	Authors
Foot blisters	Carrying heavy loads	Lower carried loads Load distribution more evenly around body centre of mass	Knapik et al., 1993; and Reynolds et al., 1990
	Moist skin	Acrylic, nylon or polyester inner sock; thick, snug, dense weave outer sock Wear polyester sock inside a very thick wool/polypropylene sock Antiperspirants	Akers and Sulzberger, 1972; and Knapik et al., 1995
	Frictional forces	Spenco shoe insoles	Smith et al., 1985; and Spence and Shields, 1968
	Skin vulnerability	Precondition feet through physical training and road march practice	Knapik et al., 1995

Injury	Risk Factor	Preventive Measure	Authors
Metatarsalgia	Walking with heavy loads	Precondition feet through physical training and road march practice Reduce load mass and volume of training	Kinoshita, 1985
Stress fractures	Female gender	Precondition feet through physical training and road march practice	Brudvig et al., 1983; and Jones et al., 1989
	White ethnicity	–	Brudvig et al., 1983
	Older age	–	Brudvig et al., 1983
	Taller body stature	–	Gilbert and Johnson, 1966
	Prior physical inactivity	Precondition feet through physical training and road march practice	Gardner et al., 1988; and Gilbert and Johnson, 1966
	Load carry distance	Gradual onset in the intensity and volume of weight bearing exercise	Jones et al. 1989; and Vogel et al., 1994
Knee pain	Load carriage	Lower extremity strengthening and stretching	Dalen et al., 1978; and Knapik et al., 1992
Low-back injuries	Heavy loads	Load distribution more evenly around body centre of mass Reduce load mass Trunk and abdominal strengthening	Reynolds et al., 1990
Rucksack palsy	Heavy loads, load distribution causing compression by shoulder straps	Framed rucksack Use of hip belt on rucksack Load shifting using strap adjustments	Bessen et al., 1987; and Wilson, 1987
	Longer carriage distances	Lower training distances, aim at intensity in stead of volume	Bessen et al., 1987; and Reynolds et al., 1990
Local discomfort and fatigue	Heavy loads and long distances	Change training road marches; take the load off the soldiers back	Dalen et al., 1978; and Knapik et al., 1991
	Design of the pack system	Wear pack with hip belts	Holewijn, 1990, and Holewijn et al., 1992

Measures to prevent injuries related to loaded carriage do not stand by themselves. They form part of what is called a sequence of prevention (Dijk, 1994). First the problem must be identified and described in terms of incidence and severity injuries. Then the factors and mechanism that play a part in the occurrence of the specific injuries have to be identified. The third step is to introduce measures that are likely to reduce the future risk and/or severity of injuries. This measure should be based on the etiological factors and the mechanisms as identified in the second step. Finally the effect of the measures must be evaluated.

Vogel et al., (1994) mentioned a number of preventive strategies related to march injuries that have gained acceptance in the military:

- Gradual progressive increases in frequency, duration and intensity of aerobic training activities, including loaded marching;
- Adequate rest given between training sessions;
- Use of adequate shoes;

- Warming-up and stretching prior to exercise sessions;
- Run or speed march on soft, even surface; and
- Avoid excessive overtraining.

3.9 MARCH PERFORMANCE, GUIDELINES TO FIELD COMMANDERS

"*The fighting value of a soldier is in inverse proportion to the load he carries*" Cathcart et al., (1922).

Load carriage ability is a mission essential task for many soldiers. A common mission for Special Operations Forces is surveillance-reconnaissance. In this type of operations soldiers execute an airborne or sea insertion into a hostile area, conduct a road march to an objective site and perform observations or other information gathering activities. On completion of the mission the soldier walk to a pick-up site. The road march is a critical aspect of this type of operation and because of the equipment needed, soldiers typically carry very heavy loads. This equipment may include communication gear, weapon systems, site preparation material, subsistence items, and protective equipment (Kanapik et al., 1993).

Soldiers on manoeuvres or in combat operations are often required to traverse a variety of terrain, including thick brush, at self paced (rather than fixed-paced) velocities while carrying basic fighting and subsistence loads. Therefore, the capability of assessing and predicting troop mobility over a variety of terrains while carrying loads is an important military concern for combat operations (Evans et al., 1980).

Performance in the context of load carriage means:

- The ability to complete the road march as rapidly as possible; and
- The ability to complete essential soldiering tasks during and/or at the end of the march.

3.9.1 Ability to Complete the Road March as Rapidly as Possible

Shoenfeld et al., (1978) studied 20 trained young men (VO_2max 57 $ml \cdot kg^{-1} \cdot min^{-1}$) during road marches of 6 and 12 km with a back-pack load of 30 or 35 kg. The aim was to search for an optimum backpack load for short distances, which would enable a person to perform strenuous physical tasks later. The study suggests that the optimal back-pack load for healthy young men, marching at 6 km/h on a paved level road to be 30 kg for 12 km and 35 kg for 6 km. As criteria for acceptable carried load, they used heart rate during marching (<160 beats/min), serum glucose concentration maintained at its initial value, no change in post march aerobic power performance, no change in serum muscle enzyme concentration, and subjective rating of persons about the difficulties in performing the tasks.

Harper et al., (1997) examined the relative performance of men and women on a maximal effort load carriage task. Men were significantly faster, about 20%, than women in completing maximal effort marches of 10 km with loads of 18 kg, 27 kg and 36 kg. For both males and females, the march with the 36-kg load took longer to complete than with either the 18-kg or 27-kg load.

Female soldiers had difficulty maintaining a pace while carrying 36-kg load. They completed the first part of the march significantly faster than either the third or forth segment. Hughes and Goldman (1970) postulated that a weight of 40 – 50% of the body weight was tolerable during walking with an average speed of 5 km/hour. The 36-kg load was within this range for men, but it was higher for the female subjects (59% of female body weight). The females began the march at a pace of 5 km/hr, they were unable to maintain the pace.

Knapik et al., (1993) studied the road marching performance of soldiers carrying various loads. Subjects were 21 Special Forces Soldiers who performed individual road marches carrying three loads (34, 48 and

61 kg) in the large ALICE back pack (All-purpose Lightweight Individual Carrying Equipment). Loads were the total mass of equipment and clothing on the soldier's body. All marches were 20 km in length and soldiers were asked to complete the distance as rapidly as possible. Cumulative road-march times at each checkpoint are shown in Table 3-12. These road-march times are the total time, which includes rest times of 0, 3 and 5 minutes for 34-, 48- and 61-kg loads respectively.

Table 3-12: Descriptive Statistics on Cumulative Road-March Times on 20-km Marches with Different Loads

Load		4 km	8 km	12 km	16 km	20 km
34 kg	M	33	65	99	135	171
	SD	5	10	16	23	31
48 kg	M	40	80	124	171	216
	SD	7	11	18	28	34
61 kg	M	44	91	148	199	253
	SD	4	10	32	19	26

A planner can estimate the range of times in which a unit or 95% of the unit should be able to complete the foot march by manipulating the mean and standard deviation for a given distance and load. To get the extreme range for the fastest soldiers the planner multiplies the SD (standard deviation) by two and adds this value to the mean. To get the extreme range of the slowest soldiers the planner multiplies the SD by two and subtracts this value from the mean. The resulting values represent the range in which 95% of the soldiers should be able to complete the march. Knapik et al., (1993) illustrated this with the following example. Assume a soldier is wearing a 34 kg and needs to travel on foot 8 km as quickly as possible. The best estimate of his time is 65 minutes. The SD is 10 min and two times this value is 20 min. Adding and subtracting this value from 65 min shows that 95% of soldiers should be able to complete the march between 85 and 45 min.

They also developed a table to estimate how additional loads may affect maximum effort march times. Slopes of regressions of loads on march times are shown in Table 3-13. These slopes represents the changes in march times (min) for a given change in load (kg). Thus, if a soldier is travelling 16 km, 5 additional kg of load will increase the time to complete the march with 12 minutes.

Table 3-13: Slopes of the Regression of Load on March Time (Slopes Represent the Change in March Time for a Given Change in Load) (Knapik et al., 1993)

Distance (km)	Slope (min/kg)
0 – 4	0.4
0 – 8	1.0
0 – 12	1.8
0 – 16	2.4
0 – 20	3.0

These tables are of practical use for field commanders who want to make an estimation of total march times of their soldiers. However, cautions are appropriate with regard to the use of the tables (Knapik et al., 1993). The data was collected on Special Forces soldiers travelling in daylight on mixed paved and dirt roads and carrying loads between 34 and 61 kg. Therefore the tables are most appropriately used with this type of soldiers under comparable conditions. Mean physical characteristics and physical fitness of the soldiers in this study were: age 30 years, height 176 cm, body weight 88 kg, body fat 21%, 3.6 km run 13.7 min, estimated VO_2max 54 ml•kg^{-1}•min^{-1}. The loads in this study refer to total load. It is assumed that rucksack weights are 15, 28 and 42 kg, with the remainder of the loads being clothing and equipment carried outside the rucksack. The soldiers paced themselves to complete the 20-km distance. Thus the march times at distances shorter than 20 km may be slightly faster than what soldiers actually performed.

In their report (Knapik et al., 1993) produced a table to estimate maximal effort march times in different terrain (Table 3-14). The calculations are based on the equation of Pandolf et al., (1977).

Table 3-14: Estimates of Maximal Effort March Times in Different Terrain for Male Soldiers (Taken from Knapik et al.,1993)

		Distance (km)				
Terrain	**Load (kg)**	**4**	**8**	**12**	**16**	**20**
Dirt	34	35	68	104	141	179
	48	42	84	130	179	226
	61	46	96	156	209	266
Light Brush	34	36	71	108	148	187
	48	44	88	136	187	237
	61	48	100	162	218	276
Hard Pack Snow	34	38	74	113	154	195
	48	46	91	142	195	246
	61	50	104	168	226	188
Heavy Brush	34	40	80	121	165	210
	48	49	98	152	210	265
	61	54	112	182	244	310
Bog	34	44	87	133	181	229
	48	54	108	166	229	290
	61	59	122	198	267	339
Sand	34	48	94	143	195	248
	48	58	116	180	248	313
	61	64	132	214	288	366
Soft Snow (25 cm)	34	60	118	180	245	310
	48	72	145	225	311	392
	61	80	166	270	363	461

As loads increased, march times increased. This is in line with findings in both laboratory studies (Hughes and Goldman, 1970; Myles et al., 1979; and Patton, 1991) and field studies (Mello et al., 1988; and Knapik et al., 1993), showing that subjects self pace at slower velocities with heavier loads.

During military backpack activities endurance time is determined by several factors, such as VO_2max, strength, body temperature, musculo-skeletal strain, and muscle glycogen stores (Aunola et al., 1990; Edwards et al., 1972; Ekblom et al., 1968; Bergstrom et al., 1967; Holewijn, 1990; Hurley et al., 1986; and MacDougall et al., 1974). However the first two factors are believed to be the most important ones.

When requested to work hard for 1 – 2 hours at self-paced rates while conducting simulated military operations including carrying loads in the field, physically fit soldiers will select a relative oxygen uptake of 40 – 50% VO_2max (Hughes and Goldman, 1970; Soule and Levy, 1972; Evans et al., 1980; and Levine et al., 1982). Evans et al., (1980) reported that the rate of voluntary hard work depends upon aerobic capacity. The best predictor of speed on each terrain for this work of 1 to 2 hours duration is 45% VO_2max. Men and women worked at nearly the same percentage of their maximum aerobic power. The absolute energy costs for the males and females during the self-pacing marching activities were 549 W (472 kcal/h) and 365 W (314 kcal/h), respectively. For men, this is in agreement with the finding of Hughes and Goldman (1970) and Soule and Levy (1972) who reported that men self-paced at an energy expenditure of approximately 495 W (425 kcal/h) regardless of the specific terrain and external load.

Jorgensen (1985) reviewed the literature and, based on this, he suggested that the upper general acceptable tolerance limit for dynamic work over an 8-hour working day is to be 50% VO_2max in trained subjects. In this context, acceptable indicates that the work can be continued at a constant work pace throughout the day, without any change in homeostasis, e.g. no increase in arterial lactate concentration and heart rate.

Myles et al., (1979) evaluated self-pacing walking (Exercise Fastball, 204 km in 6 days) of French infantry males for more prolonged periods (6.5 hours per day for 6 days), which is reflective of the situation for the military in continuous operations. The soldiers maintained an average energy expenditure equal to 32% of VO_2max, or 384 kcal/h during the march. This energy expenditure is close to the 425 kcal/h suggested as the maximum hard work adopted voluntarily by physically fit young men (Hughes and Goldman, 1970; and Nag et al., 1978). Myles et al., (1979) concluded that fit young soldiers will self-pace at 30 – 40% VO_2max and will continue to do so for at least 6 days. Also, Saha et al., (1979) reported that 35% VO_2max could be considered as a reasonable relative workload for sustained physical activity of 8 hours in duration.

Therefore, it would seem reasonable to conclude that relative percent VO_2max selected for self-paced physical work may be closely related to the work duration. Levine et al., (1982) conclude from their literature survey that as the duration of exercises increases from 1 to 2.5 to 6.5 hours, individuals appear to select decreasing relative energy expenditure from 46 to 40 to 36% of VO_2max.

Table 3-15: Relative Intensity During Prolonged Self-Paced Hard Physical Exercise (Loaded Marching)

Duration of March (Hours)	Relative Intensity Self Paced % VO_2max	Energy Expenditure Male Soldier (kcal/hr)	Energy Expenditure Female Soldier (kcal/hr)
1	46	549	364
2.5	40	477	317
6.5	36	429	285

In military populations "normal" VO_2max ranges between 3.5 and 4.2 l/min with an average relative oxygen uptake of 53 ml•kg^{-1}•min^{-1} for male soldiers. For female soldiers VO_2max varies between 2.0 and 2.8 l/min with an average relative oxygen uptake of 44 ml•kg^{-1}•min^{-1} (Dijk, 1994). Using the 75 kg man as a model and 36% VO_2max as the energy expenditure rate over several days, the average male soldier could perform continuously (with some rest pauses) at an average energy expenditure rate of 429 kcal/h. The average female soldier with a body weight of 60 kg, could perform at an average energy expenditure rate of 285 kcal/h (1 l oxygen is 5 kcal).

If the march duration is about 2.5 hours the suggested energy expenditures are 477 and 317 kcal/h respectively for male and female soldiers. Based on the formula of Pandolf et al., (1977) possible combinations of speed and load for male and female soldiers are shown in Tables 3-16a and 3-16b.

Table 3-16a: Combinations of March Speed and Loads for March Duration of 2.5 Hours, Based on an Energy Expenditure of 477 and 317 kcal/hr for Respectively Male and Female Soldiers (Pandolf et al., 1977, blacktop road). Soldiers are supposed not to be exhausted at area of destination

Male Soldier Body Weight 75 kg	Female Soldier Body Weight 60 kg
5.5 km/h load 36 kg	5.5 km/h load 17 kg
5.0 km/h load 46 kg	5.0 km/h load 26 kg
4.5 km/h load 55 kg	4.5 km/h load 34 kg
4.0 km/h load 63 kg	4.0 km/h load 41 kg

Table 3-16b: Combinations of March Speed and Loads for March Duration of 6.5 Hours, Based on an Energy Expenditure of 429 and 285 kcal/hr for Respectively Male and Female Soldiers (Pandolf et al., 1977, blacktop road). Soldiers are supposed not to be exhausted at area of destination

Male Soldier Body Weight 75 kg	Female Soldier Body Weight 60 kg
5.5 km/h load 27 kg	5.5 km/h load 8 kg
5.0 km/h load 38 kg	5.0 km/h load 18 kg
4.5 km/h load 47 kg	4.5 km/h load 27 kg
4.0 km/h load 55 kg	4.0 km/h load 35 kg

Speed of movement, in combination with the weight of the load carried, are important factors in causing exhaustion. Figure 3-3 shows the length of the time that work rates can be sustained before soldiers become exhausted. A burst of energy expenditure of 900 to 1000 kcal per hour can only be sustained for 6 to 10 minutes. A level of 300 kcal/min energy expenditure appears to be a critical value for prolonged work over 8 – 9 hours for a soldier of about 60 kg with a maximal oxygen uptake of about 2.6 litres • min^{-1} (see also Table 3-15).

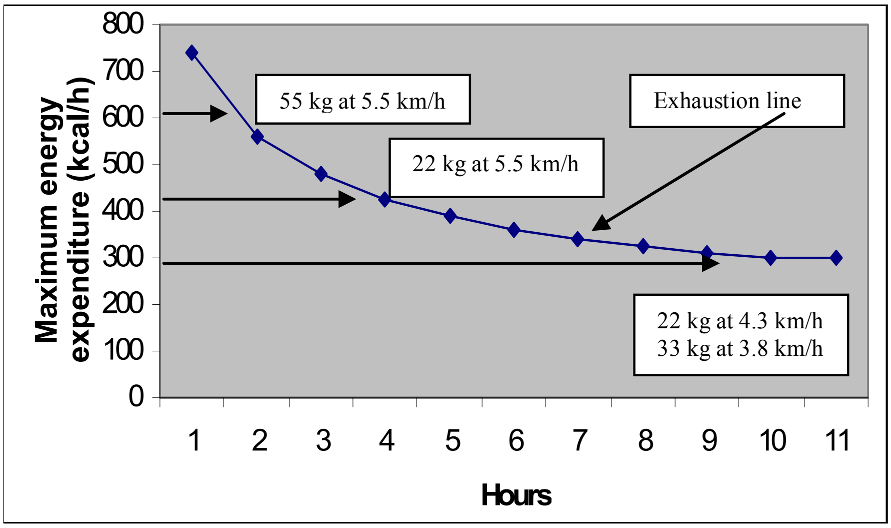

Figure 3-3: Endurance Time vs. Work Rates (Based on FM 21 – 18 Department of the Army, 1993).

When carrying loads during approach marches a soldier's speed can cause a rate-of-energy expenditure of over 300 kcal per hour. March speeds must be reduced when loads are heavier to stay within reasonable energy expenditure rates. Fighting loads must be light so that the bursts of energy available to a soldier are used to move and to fight, rather than to carry more than the minimum fighting equipment (Department of the Army US, 1993).

Based on a sustainable energy expenditure level of 429 or 300 kcal/hour for prolonged work (about 36% of VO_2max), combinations of load carried and velocity can be calculated using the equation of Pandolf et al., (1977). Figures 3-4a and 3-4b show speeds that are sustainable with given loads, which results in an energy expenditure of 429 and 300 kcal per hour. These energy expenditure rates are representative of average male and female soldiers who have to traverse to the area of destination in about 6 to 8 hours, and who are still physically able to do their assigned tasks.

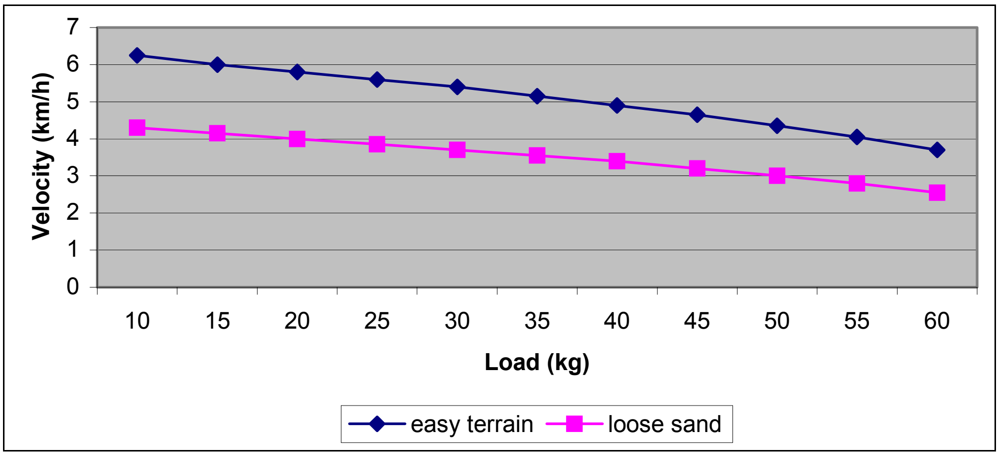

Figure 3-4a: March Speeds and Loads at an Energy Expenditure of 429 kcal Per Hour, Soldier Body Weight 75 kg, Terrain Factor 1 (black top) vs. 2.1 (loose sand) (Pandolf et al., 1977).

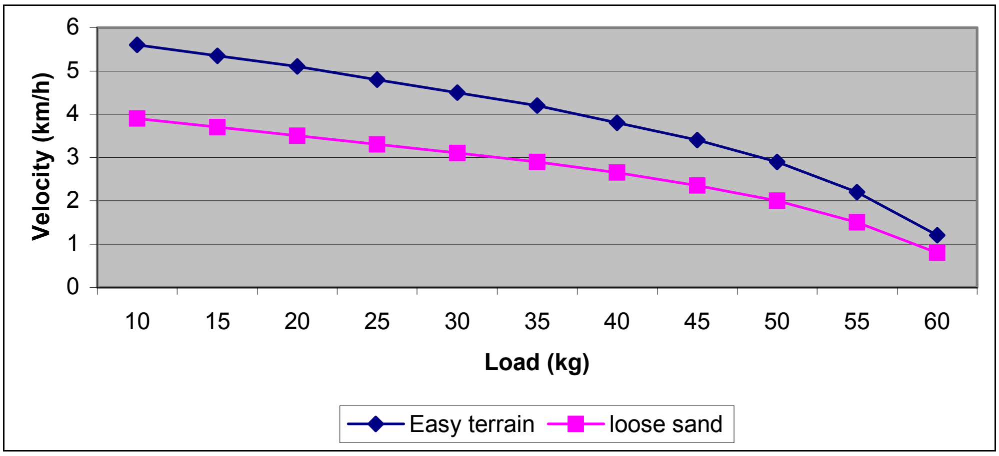

Figure 3-4b: March Speeds and Loads at an Energy Expenditure of 300 kcal Per Hour, Soldier Body Weight 60 kg, Terrain Factor 1 (black top) vs. 2.1 (loose sand) (Pandolf et al., 1977).

As velocity increases, the efficiency of walking becomes lower than running. Above a speed of about 8 km per hour unloaded running is more efficient than unloaded walking (Margaria et al., 1963; and Keren et al., 1981). With a load of 20 kg, the average load in practice during marches, the breaking point is

7.8 km per hour (Keren et al., 1981). Smaller subjects had a breaking point between walking and running (with 20-kg load) at a lower speed (6.5 km/h) than more robust subjects (8.3 km/h). It is of practical importance that without load and at speeds less than 8.2 km/h, it does not matter whether the individual runs or walks. At higher speeds the difference is critical, and soldiers are liable to be exhausted rapidly if they do not run but continue to walk. This effect is more pronounced while carrying a load, especially if the load constitutes a high percentage of body weight.

The study of Koerhuis et al., 2005 studied the relationships between endurance time and load carriage with very heavy loads. The soldiers carried loads relative to individual determined maximal load carrying capacities (MLCC). In addition the best predictors of endurance time were determined.

To determine MLCC the load carried was increased by 7.5 kg every 4 minutes until exhaustion, starting with a load that equals body mass. The marching velocity and gradient were kept constant at 3 km/h and 5%, respectively. Endurance time was determined carrying 70, 80 or 90% of MLCC. Twenty-three male combat soldiers participated. Mean anthropometric data of their subjects were: height 179.8 cm (SD 6.1), body weight 80.8 kg (SD 7.9), fat percentage 16.6 % (SD 4.5).

Maximal load carriage capacity was on average a 102.6 kg (SD 11.6). A significant difference was found in endurance times between the different load conditions at 70, 80 and 90% of MLCC (Table 3-17). Endurance time decreased with increased load.

Table 3-17: March Endurance Times with Different Load Conditions

% of MLCC	Load Carried ± SD	Endurance Time ± SD
70% MLCC	72.5 kg ± 7.5	40.9 min ± 17.2
80% MLCC	81.0 kg ± 8.8	24.5 min ± 7.4
90% MLCC	93.3 kg ± 10.1	17.7 min ± 5.8

This study indicated that during marching with heavy loads, soldiers need to be individually loaded, relative to their own MLCC. This loading strategy resulted in a more homogeneous march performance, endurance time, for a group of soldiers, compared with carrying the same absolute load by each soldier. The march performance with each soldier carrying the same absolute load (80 kg) load varied between 11.3 and 65 min (mean 30.2 minutes SD 16.1). Redistributing the load according to MLCC resulted in endurance times, varying between 13.4 and 45 min (mean 28.3 SD 8.8). In military operations the weakest person determines the group performance. Although the average endurance time remained the same, the standard deviation was twice as low, implying that the group performance improved markedly by redistributing the load according to MLCC. Redistributing the load according to body weight, which is a more practical criterion in the field, is also a better option than loading soldiers with the same absolute load. The average endurance time was 26.8 min with a standard deviation of 11.3 min, range 13.4 and 50 minutes.

3.9.2 The Ability to Perform on Essential Soldiering Tasks During and/or After the March

How well soldiers are able to perform military tasks during load carriage or after completion of a load carriage traverse is an issue vital to military operations. Performance appears to be influenced by load, volume and load distribution.

Knapik et al., (1990) studied soldier performance and mood states following an extremely strenuous road march of 20 km, carrying a total load of 46 kg. Mean physical characteristics of the soldiers participating were: age 21 years, height 178 cm, body weight 76 kg and body fat 15.7%. Following the march, fatigue was elevated 82% and vigor decreased 38% as measured by the POMS (Profile of Mood States).

Compared to pre-march values, post-march marksmanship accuracy decreased 26% for number of target hits and 33% for distance from the centroid of the target (distance of 25 m). The decrements in marksmanship are presumably due to small movements of the rifle resulting from fatigue of the upper body muscle groups, an increase in body tremors due to fatigue or elevated post-exercise heart rate or respiration.

The grenade throw and vertical jump tests were used to evaluate explosive strength and power. Maximal grenade throw distance decreased 9%, and there was no change in maximal vertical jump height. Activities like road marching do not appear to affect leg power.

It was concluded that when soldiers perform a strenuous road march with a heavy load, leaders could expect mood changes and decrements in essential soldier skills, which may significantly impact on military effectiveness.

Amos et al., (2000) reported on the physiological and cognitive performance of soldiers undertaking routine patrol and reconnaissance activities. Data were obtained during a patrol and a reconnaissance exercise followed by a short assault. During the patrol of 1.30 hrs, soldiers carried a total weight of about 30 kg. During the reconnaissance phase of 1.15 hrs, soldiers only carried webbing with water bottles and personal weapon. Oxygen consumption during the patrol was in the range of 2.5 to 3.2 litres – min^{-1}. Peak VO_2 levels greater than 3.0 litres • min^{-1} during patrol indicate that the soldiers were working hard. The VO_2 levels during the reconnaissance phase were 1.5 to 2.0 litres • min^{-1} and were generally lower than those during patrol. The soldiers displayed no evidence of deterioration in cognitive performance measured by a speed and accuracy test and State-Trait Anxiety Inventory (STAI).

Knapik et al., (1990) studied male infantry soldiers during a 5-day simulated combat operation requiring both offensive and defensive manoeuvres on foot. Soldiers carried all necessary equipment and supplies for 5 days. Total weight carried was about 25 – 29 kg, including a rucksack of 9 – 13 kg. They noticed a decline in upper-body exercise capacity and lower-body strength (8 – 10%). The decrements were attributed to the loads carried by the soldiers. Harper et al., (1997) reported a decrement in grenade throw distance as a result of a maximal effort march of 10 km with a load of 18 – 36 kg. This may be due to a nerve entrapment syndrome (Bessen et al., 1987; and Wilson, 1987) or pain in the shoulder area resulting from pressure of the rucksack straps.

Martin and Nelson (1985) examined the effect of carrying typical military loads of varying magnitude on the combative movement performance of male and female subjects. The subjects performed a series of tests that included a 22.9-meter sprint, standing long jump, agility run, reaction movement test and a ladder climb. The tests were performed under different load conditions ranging from a baseline condition (no load) to one of 37 kg. The results demonstrated a fairly consistent load effect on the performance of the men and women. In general, the decrease in performance was approximately linearly related to the increase in load.

Table 3-18: Decrements in Performance Related to Increase in Load Carried (Martin and Nelson, 1985)

Test	Load Condition 18 kg		Load Condition 37 kg		Female/Male Ratio Performance Load Condition 37 kg
	Female	Male	Female	Male	
22.9-m sprint	23%	17%	40%	29%	0.76
Standing long jump	– 17%	– 13%	– 33%	– 24%	0.82
Agility run	24%	14%	50%	36%	0.72
Reaction movement test	9%	6%	19%	15%	0.86
Ladder climb	6%	3%	126%	39%	0.41

The ladder climb was the only test of the five, which required a considerable involvement of the arms in the performance of the task. The greater female- male performance differences in the ladder climb, under all load conditions but especially at higher load conditions, may be related to differences between genders in upper body strength.

Laubach (1976) noted the relative strength of women compared to men varies considerably depending upon the area of the body under consideration. It was shown that female – male strength differences were significantly greater for the arms than for the legs. The heaviest load of 37 kg was added in the form of a frame-backpack system, which tended to restrict arm movements and thereby placed a greater demand on the upper extremity musculature.

Bassan et al., (2001) examined the relationship between load carriage and time to complete an obstacle course. The 500-meter long obstacle course included 20 individual obstacles representative of manoeuvres performed by soldiers during assaults and other battle drills. A substantial ($r^2 = 0.59$) linear relationship was found between total load carried and time and time to complete the obstacle course, with a slope of 7.88. That is, each additional kg carried increased completion time on the course by 7.88 sec or 4.5%.

Increasing the load carried will strongly diminish the self-paced speed of soldiers (Haisman, 1988, based on data of Hughes and Goldman, 1970).

As the load weight increases, the speed decreases proportionally, and the average energy cost per unit distance marched was found to be lowest for 30 – 40 kg of load (Table 3-19).

Table 3-19: Weight of Load and Speed when Self-Pacing Over 6.4 km

Weight of Load (kg)	0	20	30	40	50	60
Self-paced speed (km/h)	8.0	6.5	5.8	5.2	4.3	3.7
Energy cost kcal/h	587	469	457	448	395	386
Energy cost per unit distance Kcal/kg.m	1.04	0.83	0.79	0.79	0.84	0.84

3.10 LOAD MANAGEMENT

A very early report of a British Royal Commission in 1867 (cited by Soule et al., 1978) recommended a maximum load, for sustained operations, of 18 kg. In 1966 the United States Army Research Institute of

Environmental Medicine (USARIEM) concluded that loads of 35 to 45 percent of a soldier's body weight are the most desirable for sustained non-contact movements. Loads with 20 to 30 percent of a soldier's body weight are the most realistic for combat missions (from Perkins, 1986; and O'Connor et al., 1990). In determining which end of this weight range to select, leaders should also consider a soldier's physical condition. There is no absolute rule for this.

Haisman (1988) argued that there is clearly a case for setting an upper limit to the weight carried. If the load is not going to impair efficiency to a marked extent this weight limit ought to be less than 30 kg. He added that it is more logical to relate the load to the body weight. In an attempt to define the optimal load he stated that it might be impossible to define it in isolation from other relevant factors such as the velocity, grade, climate, clothing, and nature of the terrain. Also other factors like load carriage system, load distribution, and personal characteristics such as height, fat free mass, and VO_2max determine the optimal load.

Dean (2004) recommended – based on his observations in combat in Afghanistan – that units must continue their emphasis on minimising the loads that their soldiers are carrying while ensuring that their missions can still be accomplished. He recommended that units should set a maximum load of 1/3 of a Soldier's body weight and then enforce that weight as the Soldier's maximum Approach March Load. Any equipment that exceeds the maximum weight should be brought forward to the Soldier through unit transportation assets.

According to the findings of operations in Grenada, Falklands and Afghanistan, the dismounted infantryman is heavily loaded while conducting modern combat operations. Fighting loads up to 36 kg in operations in Afghanistan and Approach March Loads of 54 to 68 kg in operations in Falklands, Grenada and Afghanistan (McCaig and Gooderson, 1986; Dublik, 1987; and Dean 2004) are reported. Emergency Approach March Loads went up to 78 kg during the Afghanistan mission (Dean, 2004).

These excessive weights on the backs of the soldiers, coupled with the harsh environments proved detrimental to maximizing Soldier's performance. Despite the fact that units were going to great lengths to minimize the loads that their Soldiers were carrying, the weight of the Infantry's combat load was far too great and considerably exceeded the upper envelopes established by current Army doctrines (Dean, 2004).

There seem to be two persistent notions that lead commanders to overload their soldiers (General Burba, Chief of Infantry, 1986):

- "**Be-prepared**" – Some commanders feel their soldiers must be prepared to meet every imaginable contingency.
- "**The Supply System Will Fail**" – Other commanders conclude in advance of an operation that the supply system will fail and therefore decide that their soldiers should carry twice as much of everything.

Ideally, the commander establishes a maximum soldiers' load on the basis of his analysis of mission, enemy, troops, terrain, and time (METT-T). In doing so, the subordinate commanders have four basic risk variables to work with: minimum essential equipment, climate protection, threat protection, and mission (Mayville, 1987). Added together, these should weigh no more than the established maximum.

A soldier's minimum essential load includes his uniform, assigned weapon, and load carrying equipment. A minimum essential load is made up of the items a soldier always needs, regardless of his mission. Climate protection includes all the equipment designed to enable the soldier in severe temperature and rough terrain. Threat protection refers to equipment that guards the soldier from expected ballistic, armor, and nuclear-biological-chemical threats. The mission load is made up of munitions, food, and all the equipment required accomplishing the mission. Typically, this equipment includes ammunition, communication tools, and vision aids.

Mayville (1987) argued that to determine the right combination of climate, threat and mission equipment in addition to the essential equipment demands adequate risk-analyses of the mission and its tactical environment. The risk equation forces commanders to take along only the most important items. It implies that the success of the mission depends upon agility and a proper balance of firepower and maneuverability.

Clearly the load carried by the soldier will always be a compromise between what is physiological sound and what is operationally essential. Recent information of operations indicates however, that the modern dismounted soldier is over-burdened during combat field actions.

Dean (2004) recently warned the military leadership to take action. "If an aggressive Soldier equipment weight loss program is not undertaken by the Army as a whole, the Soldier's combat load will continue to increase and his physical performance will continue to be even more severely degraded by the loads that he carries in the world's harshest environments." He suggested that the weight of the combat load carried by the dismounted warrior can only be reduced through a combination of providing the soldiers with lighter systems while also off loading any and all equipment that is not immediately needed in a firefight, to alternate forms of transportation. His recommendations are listed in Appendix 3A-3.

In a series of articles O'Connor and Bahrke (1990) offer guidance on the various factors a commander must consider when planning the operational loads their soldiers will carry (see Appendix 3A-1). They discussed a number of approaches, based on the work of the Army Development and Evaluation Agency (ADEA) to lighten the soldier's load and increase his ability to carry his mission essential equipment:

- Lighter weight components.
- Special load-handling equipment.
- Re-evaluation of current training doctrine.
- Better soldier load-planning models.
- Special physical training programs.

Commanders should concentrate their efforts on those areas in which they can exert influence – the load planning and physical training approach. Research on load bearing has established the fact that rate at which a soldier expands energy will determine how long he can carry a given load. Commanders must therefore consider energy expenditure in determining their soldier's ability to sustain movement, while marching with heavy loads. Section 3.10.1 gives research-based guidelines for planning of loaded movements.

A properly designed and executed physical training program will have a major influence on the soldier's physical readiness for loaded road marching. A fit soldier is able to carry a heavier load, and carry it longer with less fatigue, than an unfit soldier. Also, a fit soldier will perform their critical tasks better while on the move and on arrival at the spot of destination.

3.11 CONCLUSIONS

1) Foot marches can be defined as the movements of troops and equipment mainly by foot with limited support by vehicles. They are characterized by combat readiness, ease of control, adaptability to terrain, slow rate of movement, and increased personnel fatigue. A successful foot march is when troops arrive at their destination at the prescribed time and they are physically able to execute their mission.

2) Military load carriage capacity is critical to soldier's mobility and sustainability, and ultimately, to soldier performance and survival on the battlefield.

3) Field Manual 21-18 (Department of the Army, 1990) provides guidance about recommended maximum loads and prescribed rates of march in different conditions. The combat load is the minimum mission-essential equipment required for Soldiers to fight and survive immediate combat operations. Combat loads consists of three categories: Fighting Load (limit 21.7 kg), Approach March Load (limit 32.7 kg), and Emergency Approach March Load.

4) An additional guidance states that a soldier's weight must be taken into account. The optimal load for a soldier has been determined to be 20 to 30 percent of their body weight for combat missions. The maximum load should not exceed 45 percent of the soldier's body weight for sustained non-contact movements.

5) The dismounted infantryman is heavily loaded while conducting modern combat operations. Fighting loads up to 36 kg in operations in Afghanistan and Approach March Loads of 54 to 68 kg in operations in Falklands, Grenada and Afghanistan are reported. These excessive weights on the backs of the soldiers, coupled with the harsh environments proved detrimental to maximizing soldier performance. The weight of the Infantry's combat load was far too great and considerably exceeded the upper envelopes established by current Army doctrines.

6) There are many factors that influence the ability of a soldier to carry load and road march. These include mass of load, speed of march, terrain factors such as gradient and surface type, distribution of the load, volume of the load, and the physical condition of the soldier.

7) Energy cost of backpack load carriage increases in a systematic manner with increases in body mass, load mass, velocity, grade, and type of terrain. Pandolf et al., developed an equation for predicting energy costs of locomotion with backpacks. It can provide commanders with valuable information about the physical strain of a certain loaded traverse. Choosing the right combination in load carried and speed, given certain characteristics of terrain and distance, dictates soldier's mobility and the capacity of the soldier to continue their job for an extended period of time.

8) For fairly fit individuals walking at a given speed and grade the energy cost/kg is independent of the extra weight carried. Up to limits of 30% of body weight the energy cost/kg is found to be the same for weight load and live weight. Within the range of 0 – 30 kg each kilogram carried load accounts for an average increase in oxygen uptake of 0.335 $ml \bullet kg^{-1} \bullet min^{-1}$ and a heart rate of 1.1 beats per minute.

9) Higher lean body mass and height are associated with faster load carriage.

10) Load carriage ability is not well predicted by unloaded running. Absolute VO_2max is much better related to march performance than relative VO_2max.

11) Multiple regression models to predict march performance include absolute VO_2max, muscular strength of leg extension and upper body, core strength, lean body mass and height. Explained variance of loaded march performance is in the range of 56 – 71 percent.

12) Testing of physical fitness and readiness of soldiers and units is essential for military field practice and training. The most important reasons are to identify weaknesses, monitor progress, provide feedback, and educate commanders and soldiers.

13) Several road march tests are currently in use by NATO-countries. Basically three types of tests are used:

i) Loaded march time trials with loads varying between 5 to 68 kg over distances of 5 to 20 km. The loads are chosen to approximate the different types of combat loads – Fighting Load, Approach March Load and Emergency Approach March Load;

ii) Incremental loaded road march tests; and

iii) Submaximal testing in which pass/failure scores based on operational task or job specialities are imposed.

14) In military training and operational setting the loaded-march task varies greatly. Depending on the task variables a different mix in fitness components – muscular strength, muscular endurance and aerobic fitness – is stressed. This should be borne in mind when selecting a specific road marching test to monitor or evaluate the physical readiness and training of a unit.

15) The optimum training to improve marching performance appears to be a combination of resistance training, endurance training and task repetition. Programs that only focus on aerobic fitness or muscular strength were not effective.

16) When planning training schedules, units should regard 2 times per month as a minimum frequency for road march training. A 10-day cycle appears to be optimal.

17) Training effects for loaded road marching, time trials, are moderate and in the order of 5 – 15 percent. Probably the capacities to continue the task for prolonged time – given a certain load, speed and terrain – is much more improved.

18) Excessive marching may be costly in terms of training time and increased risk of injuries. Depending on the operational requirements, short but intensive training is a very cost effective approach and the benefits in terms of progress in road marching performance with heavy weights are substantial.

19) Medical problems and injuries associated with load carriage can adversely affect an individual's mobility, and in military operations, reduce the effectiveness of an entire unit. Common types of injuries include blisters, plantar fasciitis, achilles tendonitis, shin splints, stress fractures, anterior compartment syndrome, chondromalacia patellae and low-back strain.

20) Factors commonly implicated in marching injuries include training program parameters, footwear, training surface, initial low level of fitness/inactivity, anatomical anomalies, inappropriate flexibility, excess body fat, gender and age, health factors, and prior injury history.

21) Preventive strategies related to march injuries that have gained acceptance in the military:

- Gradual progressive increases in frequency, duration and intensity of training activities, including loaded marching;
- Adequate rest given between training sessions;
- Use of adequate shoes;
- Warming-up and stretching prior to exercise sessions;
- Run or speed march on soft, even surface; and
- Avoid excessive overtraining.

22) Performance in the context of load carriage means the ability to complete the road march as rapidly as possible, and the ability to complete essential soldiering tasks at the end of the march.

23) Men are significantly faster (about 20%) than women in completing maximal effort marches of 10 km in distance with loads of 18 kg, 27 kg and 36 kg.

24) Evidence-based guidelines are developed to assist field commanders in planning movement while marching with loads.

25) The average male and female soldier could perform prolonged work over 8 – 9 hours at a relative intensity of 36 percent of VO_2max. The average male soldier could perform at an average energy expenditure rate of 430 kcal/h and the average female soldier at a rate of 285 kcal/hour. If the march duration is about 2 – 3 hours the suggested relative intensity is 40% of VO_2max and the energy expenditures are 477 and 317 kcal/h for respectively male and female soldiers. A burst of energy expenditure of 900 to 1000 kcal per hour can only be sustained for 6 to 10 minutes.

26) Based on these energy expenditure levels, field commanders can calculate optimal combinations of load carried and velocity of unit movements given certain terrain factors, as grade and surface.

27) As velocity increases, the efficiency of walking becomes lower than running. Above a speed of about 8 km per hour, unloaded running is more efficient than unloaded walking. With a load of 20 kg representing the average load in practice during marches, the breaking point is 7.8 km per hour. Smaller subjects had a breaking point between walking and running (with 20 kg load) at a lower speed (6.5 km/h) than more robust subjects (8.3 km/h).

28) During marching with heavy loads, soldiers need to be individually loaded, relative to their own Maximum Load Carry Capacity. This loading strategy resulted in a more homogeneous march performance, endurance time, for a group of soldiers, compared with carrying the same absolute load by each soldier.

29) Redistributing the load according to body weight which is a more practical criterion in the field, is also a better option than loading soldiers with the same absolute load.

30) When soldiers perform a strenuous road march with a heavy load, leaders could expect mood changes and decrements in essential soldier skills – e.g. marksmanship, and grenade throwing – which may have significantly impact on military effectiveness.

31) Load carriage has a fairly consistent negative momentary effect on military physical task activities like sprinting, jumping, agility, ladder climbing. In general, the decrease in performance is approximately linearly related to the increase in load.

32) An aggressive combined approach is needed to lower the weight of the combat load worn by the dismounted soldier. It can only be reduced through a combination of providing the soldiers with lighter systems while also off loading any and all equipment that is not immediately needed in a firefight, to alternate forms of transportation.

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Appendix 3A-1

Factors to consider during planning of operations in which soldiers loads could have definite bearing on the outcome of the mission (O'Connor et al., 1990).

Mission Characteristics	Soldier Characteristics	Load Characteristics
1) Movement route ▪ Open march (roads/trails) ▪ Movement in cover ▪ Type of movement (walk, crouch, crawl)	1) Physical (anatomical, physiological, medical) ▪ Height/weight ▪ Body type ▪ Physical condition ▪ Nutrition/hydration status ▪ State of rest/fatigue ▪ Condition of the feet	1) Load ▪ Weight ▪ Bulk ▪ Multi-soldier loads
2) Clothing (MOPP-level, patrol)	2) Psychological ▪ Level of motivation ▪ Mood state ▪ Self-confidence ▪ Fatigue	2) Load bearing equipment ▪ Rucksack ▪ Hand carry requirements ▪ Yoke/sling ▪ Man carts
3) Schedule requirements ▪ Distance travelled ▪ Rate of movement ▪ Rest/move schedule ▪ Feeding schedule (planned, on-the-move) ▪ Post-march recovery plan ▪ Sleep plan	3) Training/conditioning ▪ Tr in preparing loads for movement ▪ Use of load bearing equipment ▪ Condition of boots and socks ▪ Experience in, arch and water discipline ▪ Experience in carrying combat loads ▪ Move/rest cycle experience under loaded condition	3) Load configuration ▪ Balance ▪ Stability ▪ Distribution

Appendix 3A-2

Factors to consider during planning of operations in which soldiers loads could have definite bearing on the outcome of the mission (O'Connor et al., 1990).

Mission Characteristics

1) Physical demands on the engagement (MOUT, obstacles, and the like)

2) Environmental characteristics

- Visibility
  - Day/night
  - Vegetation/terrain features
- Weather
  - Temperature
  - Humidity
  - Wind (speed/direction)
  - Wind chill
  - Precipitation
- Terrain characteristics
  - Altitude
  - Grade
  - Surface characteristics
  - Vegetation
- Natural irritants
  - Insects
  - Plants
  - Animals
- Artificial irritants
  - NBC considerations
  - Noise
  - Smoke
- Potable water supply

Appendix 3A-3

Factors to consider in reducing the load on the soldier's back, findings of military operations in Afghanistan (Dean, 2004).

Major Findings:

- Increased capabilities continue to increase physical burdens.
- Fit Soldiers are easily exhausted by their modern loads while operating in extreme environments.
- Body armor needs to continue to be lightened and made much more flexible.
- Unit transportation assets need to carry the bulk of the Soldier's load.
- Units need more small unit ground vehicles.
- Army level effort needs to go into reducing the Combat Load through doctrine and equipment changes. Needs unified action.

Reduce the Weight of Soldier Worn Technologies:

- All Soldiers have different jobs and carry different loads.
- Recognize that the need for most gear will not go away. Soldiers have basic needs that will remain over time.
- Make all attempts to create lightweight Soldier carried gear.
- Look to lighten ALL the gear that Soldiers carry, not just an item here or there.
- Make attempts to develop multi-functional gear to replace current one-task items.
- Follow industry and buy off the shelf, state-of-the-art gear to replace Army clunkers (GPS as example). Throw it away when it dies.
- Reinvent many staple items to shed weight (machine gun tripods, ammunition (all types), batteries, body armor, and more).
- Re-design or purchase commercial load carriage systems that support all job specialties (example = RadioTelephone Operator – no load carriage system that meets his needs).

And Take the Weight **OFF** the Soldier's Back:

- Re-think the logistical practices that the Army has been using since WWII and consider novel ways to re-supply the dismounted Soldier, to include possible daytime re-supply.
- Provide the platoon and squad with small unit logistics vehicles that can follow closely behind the unit during combat operations. Place most of the contents of the Soldier's Assault Rucksack on these vehicles. Place some of the Soldier's basic load of ammunition on these vehicles as well as specialty items.