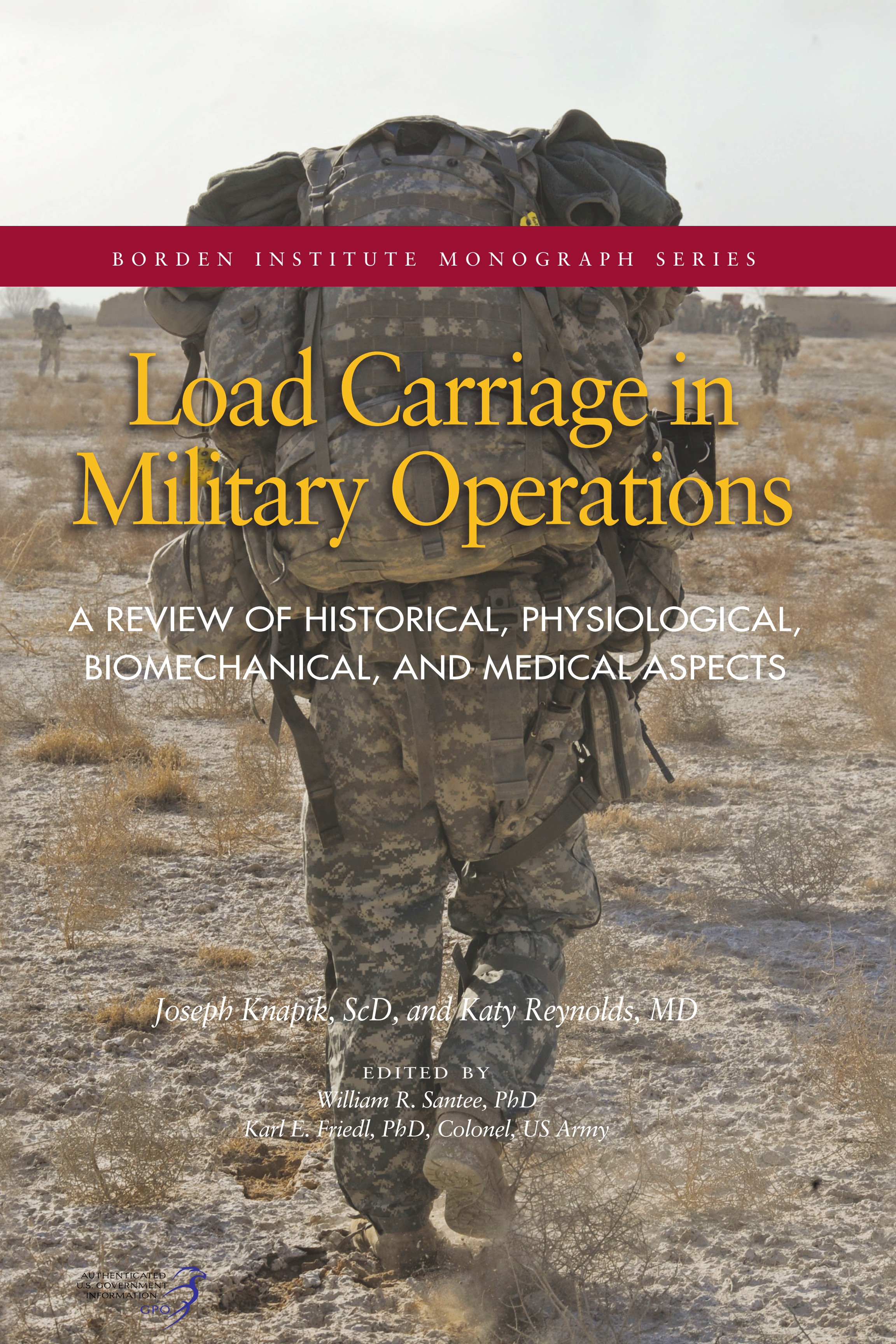

BORDEN INSTITUTE MONOGRAPH SERIES

Load Carriage in Military Operations

A REVIEW OF HISTORICAL, PHYSIOLOGICAL, BIOMECHANICAL, AND MEDICAL ASPECTS

Joseph Knapik, ScD, and Katy Reynolds, MD

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Making loads lighter, improving load distribution, using appropriate physical training, selecting proper equipment, and choosing specific techniques directed at injury prevention will all facilitate load carriage. Suitable changes will allow service members to continue missions at lower energy costs and with fewer injuries, and be better able to perform other tasks.

Borden Institute
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US Army Medical Department Center & School

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Cover photo: Courtesy of US Air Force, TSgt Efren Lopez, photographer

Joseph Knapik is a Major (Ret), Medical Service Corps, US Army; Research Physiologist, Injury Prevention Program, US Army Public Health Command (Provisional), 5158 Blackhawk Road, Aberdeen Proving Ground, Maryland 21005-5425.
Katy Reynolds is a Colonel (Ret), Medical Corps, US Army; 8820 Burning Tree Road, Pensacola, Florida 32514.

Foreword

This monograph presents a comprehensive overview of research on soldier load carriage. The authors demonstrate broad personal research and reporting experience from both field and laboratory perspectives. This knowledge helps provide an implicit framework for categorizing and evaluating past research, as well as for planning future research efforts.

Loads carried by soldiers have been of scientific concern since around the 18th century and is a continuing problem, as recognized by soldiers operating in rugged terrain in Afghanistan today. It is perhaps shocking that, with technological advances, the problems have worsened rather than improved. Improvements in weaponry, surveillance, communications, and personal protective equipment have added to the soldier load, and this has only partially been compensated by enhanced strategies to safely and effectively manage those loads. The problem of load carriage has been reviewed by a number of military committees and organizations that have provided suggestions for reducing the stress of loads. Generally, these groups were tasked with narrowly focusing on a particular, then-timely perspective; findings were directly applicable to the issues directly at hand, but were not always of strategic value appropriate to broader scientific concerns. Thus, to some degree, developed knowledge based on load carriage has not been fully explored. Missing, to a large extent, is research on the relationship between the known state of load carriage comfort, energy cost, and ergonomic "fit," and the ongoing introduction of ancillary technologies (eg, robotics, automation, and real-time communications devices), as well as vision and hearing enhancements. This monograph provides a concrete, data-based framework needed to guide the introduction of such evolving topics into the load carriage research arena.

The section on physiology and biomechanics provides an overview of current load carriage systems and highlights information on load placement, pack frames, hip belts, and strap adjustments. Although materiel and combat developers have considered some information noted herein, other research is relatively new or has not been adequately promulgated to these developers. A stark example of potential improvements is taken from gains in female load carriage performance and comfort, once load carriage equipment was finally updated in the past decade to accommodate smaller framed women with different anthropometric dimensions than the average male.

Another section reviews the equations that quantify the impact of load distribution on the mechanics and energy cost of load carriage. This detailed contribution to the knowledge base permits the exploration of new technologies, such as virtual prototyping of new systems, to produce safer and more effective load carriage than ever before. The literature on rifle carriage and body armor is covered, as well as alternative methods of load carriage (eg, carts and motorized vehicles). Unfortunately, it is still necessary to discuss injuries associated with load carriage, and this monograph provides practical information on the signs and symptoms of these injuries, as well as treatment and evidence-based suggestions for injury prevention.

The authors worked for many years at the US Army Research Institute of Environmental Medicine (USARIEM), where much of the US research on load carriage has been conducted. They have gained broader perspectives serving with organizations such as the US Army Research Laboratory and the US Army Center for Health Promotion and Preventive Medicine (now the US Army Public Health Command).

Karl E. Friedl, PhD, Colonel, US Army
Director, Telemedicine and Advanced Technology Research Center
US Army Medical Research and Materiel Command

Rene de Pontbriand, PhD
Associate Director for Science and Technology (Ret)
Human Research and Engineering Directorate
US Army Research Laboratory

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Introduction

Because of mission requirements or the limited transportation assets of some types of units, service members must often depend on their personal mobility to move individual equipment. The carrying of loads by troops is an important aspect of military operations that can become critical in some situations. Overloading with ammunition and equipment can lead to excessive fatigue and impair the ability to fight. Military historians can cite numerous examples when heavy loads directly or indirectly resulted in reduced performance, unnecessary deaths, and lost battles (Exhibit 1).[1–4] The experience of British troops in the Falkland Islands War (1982) and US Army troops in both Grenada (1983) and Afghanistan (1999–2010) emphasizes that overloading troops is still a problem in modern warfare.[5–7]

The purpose of this monograph is to review the historical, physiological, biomechanical, and medical aspects of load carriage. Practical suggestions are offered for reducing the stress of loads on service members and for preventing and treating common load carriage-related injuries. Reviews on other aspects of load carriage are available in the works of Haisman[8] and Knapik et al.[9,10]

Exhibit 1. *Heavy Loads in Military History*

Omaha Beach, France (1944)[1]

"In the initial assault waves at Omaha Beachhead there were companies whose men started ashore, each with four cartons of cigarettes in his pack—as if the object of the operation was trading with the French. Some never made the shore because of the cigarettes. They dropped into deep holes during the wade-in, or fell into the tide nicked by a bullet. Then they soaked up so much weight they could not rise again. They drowned. Some were carried out to sea but the great number were cast up on the beach. It impressed the survivors unforgettably—that line of dead men along the sand, many of whom had received but trifling wounds. . . . No one can say with authority whether more men died directly from enemy fire than perished because of the excess weight that made them easy victims of the water. . . . This almost cost us the beachhead. Since it is the same kind of mistake that armies and their commanders have been making for centuries, there is every reason to believe it will happen again."

Grenada (1986)[2]

"Unfortunately too few commanders enforced load discipline. Consider this soldier's observation: 'We attacked to secure the airhead. We were like slow moving turtles. My rucksack weighed 120 pounds. I would get up and rush for 10 yards, throw myself down and couldn't get up. I'd rest for 10 or 15 minutes, struggle to get up, go 10 more yards, 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.' Consider another soldier's telling comment: 'I was scared I was going to get killed because I couldn't really run with that rucksack on.' Even allowing for some exaggeration by the soldiers, no one can doubt they were overloaded."

Saudi Arabia and Iraq (1990)[3]

"During Operation Desert Shield, a brigade conducted a live fire training assault to seize a bridge. The brigade commander noticed that the equipment the soldiers were carrying was interfering with the mission. At the after action review he directed the battalion commanders to investigate the weight the soldiers carried in their battalions. At the brief back one commander indicated that the average soldier in his battalion carried more than 100 pounds.

At Christmas 1990 the [2d Brigade, 82d Airborne Division] was conducting training far to the South of the front. During this relatively peaceful time, and especially as a result of the holiday, the soldiers had accumulated many items they could not take into combat. When the order came for the brigade to spearhead the French 6th Light Armored Division's attack into Iraq, the chain of command took

(Exhibit 1 *continues*)

Exhibit 1 *continued*

steps to care for the soldier's personal effects and excess baggage. They made a list of what a soldier would carry on his person (fighting load), what he would carry in his rucksack (approach march load), what he would carry in his A-bag (sustainment load), and what would go in his B-bag (contingency load). Items that did not fit in these categories, the soldier shipped home. . . . The battalions that entered the Euphrates River Valley had learned a valuable lesson as a result of their earlier training attack on the bridge. Although their fighting and approach march loads were still heavy, they knew better how to manage them. When units arrived at their landing zones, the battalions secured their rucksacks (approach march load) with a minimum guard force while the rest of the soldiers occupied their positions. As soon as practicable, soldiers went back, a few at a time, to retrieve the rucksacks. In at least one instance, a unit placed excess ammunition and water in kick-out bundles that could then be taken forward and stored in a central location for further distribution."

Afghanistan (2002)[4]

"We had extreme difficulty moving with all of our weight. If our movement would have been to relieve a unit in contact or a time sensitive mission we would not have been able to move in a timely manner. It took us 8 hours to move 5 clicks. With just the vest [Interceptor hard body armor] and LBV [Enhanced Tactical Load Bearing Vest or the MOLLE vest] we were easily carrying 80 lbs. Throw on the ruck and you're sucking."

Data sources: (1) Marshall SLA. *The Soldier's Load and the Mobility of a Nation*. Quantico, Va: Marine Corps Association; 1950. (2) Dubik JM, Fullerton TD. Soldier overloading in Grenada. *Mil Rev*. 1987;67:38–47. (3) Porter SC. The soldier's load. *Infantry*. 1992;May–June:19–22. (4) Comments from the 187th Regiment First Sergeant, Operation Anaconda.

Historical Perspective

Loads Carried During Various Historical Periods

Figure 1 shows loads that were carried by various military units in history, with emphasis on more recent times. Lothian[11] provided data on ancient military units. Until about the 18th century, troops carried loads that seldom exceeded 15 kg as they marched. Extra equipment was often moved by auxiliary transport, including assistants, horses, carts, and camp followers. The extra equipment often consisted of weapons and protection used by troops when they went into battle (eg, swords and shields). After the 18th century, auxiliary transport was deemphasized, and more disciplined armies required troops to carry their own loads. The latter-day service member often carried more equipment during the march and less when in contact with hostile forces.[2] It should be noted that most of the loads provided in Figure 1 are from estimates and literary sources. The only actually measured values are those from the Joint Readiness Training Center (in Fort Chaffe, Ark) and Operation Enduring Freedom (Afghanistan).

19th- and 20th-Century Efforts to Study Load Carriage

European Efforts

After the Crimean War, a British "Committee Appointed to Inquire into the Effects of the Present System of Carrying Accouterments, Ammunition and Kit of the Infantry Soldier" recommended that soldier

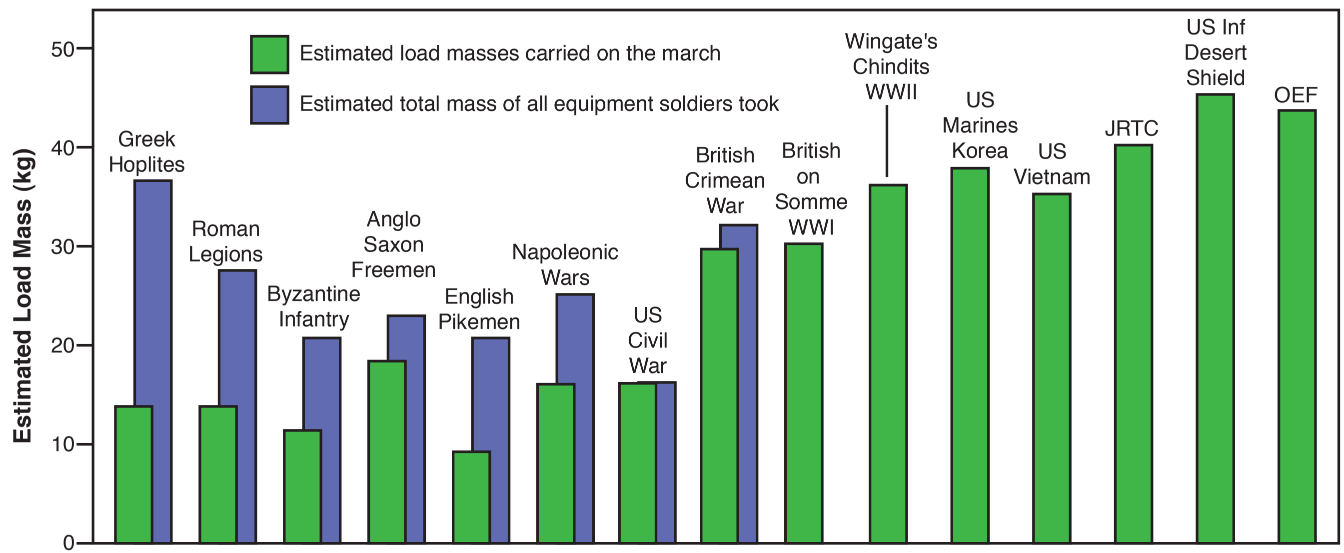

Figure 1. *Loads carried on the march by various infantry units throughout history. Inf: infantry; JRTC: Joint Readiness Training Center (Ft Chaffee, Ark); OEF: Operation Enduring Freedom; US: United States; WWI: World War I; WWII: World War II.*
Data sources: Dean CE. The Modern Warrior's Combat Load. Dismounted Operations in Afghanistan April–May 2003. Ft Leavenworth, Kan: Army Center for Lessons Learned; 2004. Downs F. The Killing Zone: My Life in the Vietnam War. New York, NY: Berkley Publishing Group; 1978. Holmes R. Acts of War. The Behavior of Men in Battle. New York, NY: MacMillan and Co, 1985. Joint Readiness Training Center. Unpublished data collected on units participating in exercises at the Joint Readiness Training Center, 1988. Lothian NV. The load carried by the soldier. J R Army Med Corps. 1922;38:9–24. Porter SC. The soldier's load. Infantry. 1992;May–June:19–22.

loads be reduced to 21 kg through the elimination of "necessaries," especially underclothing.[2,4] Studies at the Frederick Wilhelm Institute in 1895 showed that, if the weather was cool, soldiers could tolerate marching 24 km with a load mass of 22 kg. In warm weather, this test caused "minor disturbances," from which the men recovered in 1 day.[2] In 1908, a "Committee on the Physiological Effects of Food, Training, and Clothing of the Soldier" developed a much-improved load carriage system that was used in World War I. In 1920, the Hygiene Advisory Board of the British Army recommended that the soldier's load should not exceed 18 to 20 kg or one third of his body weight while marching. With the development of indirect calorimetry, Cathcart and colleagues[12] were able to study the energy cost of two men marching at a variety of paces and with a variety of load masses. They found that energy cost per mass carried was lowest when subjects carried a mass equal to 40% of their body mass.

American Efforts

There is little information about American efforts to study load carriage formally before World War II, if these efforts even existed. Under the direction of the Quartermaster General, Captain H. W. Taylor developed a soldier "payload plan." This was an attempt to unburden the soldier by providing him with only the items needed for combat. There were also attempts to develop segmented packs: if the tactical situation permitted, a portion of the pack containing nonessential equipment could be left behind.[13]

World War II led to many situations in which soldiers had to carry loads for long distances. Figure 2 shows American soldiers marching to relieve troops in the Ardennes Forest during the Battle of the Bulge. Figure 3 shows a training exercise in which a modern airman is being transported using a two-man carry, not an uncommon situation in World War II. Figure 4 shows an infantryman transporting loads by mules in Burma. Presumably drawing on many of the experiences from World War II, US Army Field Board No. 3 (Fort Benning, Ga) performed a number of studies from 1948 to 1950. Board members noted that previous work had ignored the individual soldier's mission within the military unit. In studying individual positions, they found that loads ranged from 25 kg for the rifleman to 50 kg for the ammunition carrier. In cooperation with the Office of The Surgeon General, the Board estimated how load masses should be reduced to make the soldier more combat effective. Metabolic data and stress placed on soldiers in combat were consid-

Figure 2. *American soldiers marching to relieve troops encircled in the Ardennes Forest during the Battle of the Bulge.*
Photograph: Courtesy of Olive-Drab.com. From http://www.olive-drab.com/od_history_ww2_ops_battles_1944bulge.php.

ered. Based on a literature review, the Board determined that the energy available for marching (with the basal metabolic rate subtracted) could not exceed 3,680 kcal/day. They recommended that a rifleman carry 18 kg in the worst conditions; 25 kg was recommended as the maximum march load.[14]

About a decade later, the US Army Infantry Combat Developments Agency[15,16] reinforced the weight recommendations of US Army Field Board No. 3. The agency recommended a load of 18 kg (or 30% body weight) for a conditioned fighting soldier and 25 kg (or 45% body weight) for a marching soldier. They developed the idea of "load echeloning" and defined a fighting load and an existence load.

In 1987, the US Army Development and Employment Agency (ADEA; Fort Lewis, Wa) further developed the concept of load echeloning.[17] They called the load carried by a soldier the *combat load*, defined as the mission-essential equipment required by soldiers to fight, survive,

Figure 3. *An airman being transported using a two-man carry in a training exercise. Photograph: Courtesy of the US Air Force. From http://www.af.mil/shared/media/photodb/photos/070515-F-4127S-706.jpg.*

Figure 4. *Mars Task Force mule skinners (2nd Battalion, 475th Infantry Regiment) lead mules through the swift river that impeded their progress to Bhamo, Burma, November 17, 1944. Photograph: Courtesy of Olive-Drab.com. From http://www.olive-drab.com/od_army-horses-mules_ww2.php.*

and complete their combat mission. The combat load was further divided into a *fighting load* and an *approach march load*. The fighting load was carried when enemy contact was expected or stealth was necessary. It consisted of the soldier's clothing, load-bearing equipment, helmet, weapon, rations, bayonet, and ammunition. The approach march load was carried in more prolonged operations. It included the combat load plus a pack, sleeping roll, extra clothing, extra rations, and extra ammunition. Current US Army doctrine recommends 22 kg (or 30% body weight) for the fighting load and 33 kg (or 45% body weight) for the approach march load.[18]

ADEA studied nine light infantry jobs that soldiers might have to perform in a worst-case situation. The loads carried by soldiers in these positions are shown in Table 1. ADEA[17] proposed five approaches for lightening soldier loads: (1) development of lighter weight components—however, technical developments were expected to reduce loads by only 6% overall (see Table 1);[19] (2) use of the soldier load-planning model—a computer program that aided the commander in tailoring loads through a risk analysis based on the mission, enemy, terrain, troops, and time; (3) development of specialized, load-carrying equipment (including items such as handcarts and all-terrain vehicles); (4) reevaluation of current doctrine that might affect load carriage (eg, an increased emphasis on marksmanship to reduce ammunition loads); and (5) development of special physical training programs to condition soldiers to develop more physical capability for load carriage.

Table 1. *Worst Case Loads and Projected Weights Because of New Technologies* (*Including Clothing and Personal Equipment*) *for Nine US Army Light Infantry Positions*

Position	US Army Development and Employment Agency Worst-Case Loads (kg)	Expected Weights Because of New Technologies (kg)[19]
Assistant Dragon Gunner	76	74
Assistant Machine Gunner	69	59
Radio Telephone Operator	68	64
Dragon Gunner	64	61
Rifleman	62	64
Squad Automatic Weapon Gunner	59	57
Platoon Leader	58	54
Machine Gunner	58	53
Grenadier	56	53

The first study of loads actually carried in combat was performed with a light infantry brigade (the 82nd Airborne Division) engaged in a low-intensity conflict in the deserts and mountains of Afghanistan during spring 2003. A team of infantrymen was dedicated to the data collection effort and also served to augment the combat forces. Loads were inventoried and weighed with digital scales on 15 separate occasions involving seven combat missions from April 4, 2003 to May 5, 2003. The loads carried by soldiers in each of the 29 duty positions are shown in Table 2.

Table 2. *Average Loads Carried by Light Infantry Soldiers During Dismounted Operations in Afghanistan in April and May 2003*[5]

Duty Position	Fighting Load (kg)	Approach March Load (kg)	Emergency Approach March Load (kg)
Rifleman	29	43	58
M203 Grenadier	32	48	62
Automatic Rifleman	36	50	64
Antitank Specialist	31	45	59
Rifle Team Leader	29	43	59
Rifle Squad Leader	28	43	58
Forward Observer	26	41	58
Forward Observer Radio/Telephone Operator	27	39	54
Weapons Squad Leader	28	45	60
M240 Machine Gunner	37	51	60
M240B Assistant Gunner	32	55	67
M240B Ammunition Bearer	31	53	65
Rifle Platoon Sergeant	28	41	54
Rifle Platoon Leader	28	42	53
Platoon Medic	25	42	54
Radio/Telephone Operator	29	45	No data
Mortar Section Leader	26	50	68
Mortar Squad Leader	28	58	65
60-mm Mortar Gunner	29	49	61
60-mm Mortar Assistant Gunner	25	55	No data
60-mm Mortar Ammunition Bearer	24	46	No data
Rifle Company Communication Chief	31	50	No data
Fire Support Officer	25	42	No data
Fire Support Noncommissioned Officer	24	41	65
Sapper Engineer	27	43	60
Company Executive Officer	27	42	No data
Company First Sergeant	29	41	57
Company Radio/Telephone Operator	29	44	59
Rifle Company Commander	30	44	50
Average	**29**	**46**	**60**

The emergency approach march load was defined as the load that was carried in foot operations when the terrain was “impassable to vehicles or where ground/air transportation resources are not available.” It was noted that recent improvements in ballistic protection (interceptor body armor, advanced combat helmet) had increased soldier survivability, but had decreased mobility and endurance. Body armor and the protective helmet accounted for roughly 31% of the fighting load.[5]

Load Carriage Throughout History

Many of the approaches proposed more recently for reducing soldier loads[5,17] are not new. For example, commanders and individual soldiers have practiced load tailoring throughout history. Iphicrates of Ancient Greece armed his infantry with only a wooden shield, lance, and sword. They defeated a Spartan force of heavily equipped Hoplites, presumably because of their greater agility. The Hoplites carried a load of about 37 kg into battle. In the 17th century, Gustavus Adolphus of Sweden lightened his soldiers’ loads by removing armor and shortening weapons. In the Boer Wars, the British Army carried only arms, ammunition, water, and a haversack—a total weight of 11 kg.[2] Soldiers in battle have often reduced loads on their own initiative. During the highly successful Shenandoah campaign, the Confederate troops under Stonewall Jackson discarded extra clothing, overcoats, and knapsacks. They carried only rifles, ammunition, food, a blanket (or rubber sheet), and the clothing they wore.[2,3] American paratroopers entering Normandy in 1944 exited the aircraft with a load of about 36 kg. However, once on the ground, they quickly discarded equipment they considered unnecessary.[3]

A wide variety of load-carrying systems have also been used throughout history. The Greek Hoplites used helots (serfs in ancient Sparta) to carry their equipment on the march. Carts and packs were used by Roman legions. Oliver Cromwell’s armies used “pack boys.” Napoleon used carts whenever possible to relieve his soldiers of their march loads. Camp followers also carried much of the soldiers’ load during various wars.[1,2]

Physical training has been used to improve marching with loads. Roman legionnaires are estimated to have performed road marching three times per month at a rate of about 5 km/h carrying a 20-kg pack over a 32-km distance. In Cromwell’s army (circa 1640), pay was contingent on marching 24 km on a regular basis. During World War I, the French

Table 3. *Physical Characteristics of Soldiers and Recruits*

Sample	Height (cm)	Weight (kg)	Body Mass Index (kg/m²)	Fat-Free Mass (kg)	Body Fat (%)
French Samples					
French (Crimean War)[2]	163	56	21.1	NA	NA
French (Post-WWI)[2]	163	NA	NA	NA	NA
British Samples					
British (Post-WWI)[2]	168	59	20.9	NA	NA
British recruits (1978)[(1)]	175	70	22.9	NA	NA
British infantry (1976)[(1)]	175	73	23.8	NA	NA
US Samples					
US male soldiers (1864)[(2)]	171	64	21.9	53*	16.9*
US male soldiers (1919)[(2)]	172	66	22.3	55*	15.7*
US male soldiers (1946)[(2)]	174	70	23.1	60*	14.4*
US male soldiers (1976)[(3)]	175	73	23.8	59†	19.5†
US male soldiers (1984)[(2)]	174	76	25.1	63‡	17.3‡
US male soldiers (1986)[21]	177	76	24.2	NA	NA
US male soldiers (1988)[130]	176	76	24.5	63*	15.9*
US male soldiers (1989)[23]	178	77	24.4	64‡	15.9‡
US male soldiers (2004)§	177	81	25.7	NA	NA
US male soldiers (2005)[(4)]	178	83	26.4	68¥	17.7¥

*Estimated from circumference measures.[(5)]
†Estimated from skinfolds.[(6)]
‡Estimated from densiometry.[(7)]
§Previously unpublished data, Fort Campbell, Kentucky.
¥Estimated from dual X-ray absorptiometry.[(8)]
NA: not available; WWI: World War I
Data sources: (1) Vogel JA, Crowdy JP. Aerobic fitness and body fat of young British males entering the Army. *Eur J Appl Physiol*. 1978;40:73–83. (2) Friedl KE. Body composition and military performance: origins of the Army standards. In: Marriott BM, Grumstrup-Scott J, eds. *Body Composition and Military Performance*. Washington, DC: National Academy Press; 1992. (3) Vogel JA, Patton JF, Mello RP, Daniels WL. An analysis of aerobic capacity in a large United States population. *J Appl Physiol*. 1986;60:494–500. (4) Sharp M, Knapik JJ, Walker LM, et al. Changes in physical fitness and body composition following 9 months deployment to Afghanistan. *Med Sci Sports Exerc*. 2008;40:1687–1692. (5) Vogel JA, Kirkpatrick JW, Fitzgerald PI, Hodgdon JA, Harman EA. *Derivation of Anthropometry Based Body Fat Equations for the Army's Weight Control Program*. Natick, Mass: US Army Research Institute of Environmental Medicine; 1988. Technical Report 17-88. (6) Durnin JV, Womersley J. Body fat assessed from total body density and its estimate from skinfold thickness: measurements on 481 men and women aged 16 to 72 years. *Br J Nutr*. 1974;32:77–97. (7) Fitzgerald PI, Vogel JA, Miletti J, Foster JM. *An Improved Portable Hydrostatic Weighing System for Body Composition*. Natick, Mass: US Army Research Institute of Environmental Medicine; 1988. Technical Report T4/88. (8) Lohman TG. Dual energy X-ray absorptiometry. In: Roche AF, Heymsfield SB, Lohman TG, eds. *Human Body Composition*. Champaign, Ill: Human Kinetics; 1996.

Chasseurs (infantry), carrying a "light kit," marched more than 13 to 18 km two times per week. Recruit training in Germany during World War I included taking an initial 10-km march, with 1 km added weekly until recruits were marching 20 km with a "full kit."[2] McMichael[20] gives a brief description of the training of Wingate's Chindits (from the Burmese word “chinthe” [or lions]—also known as “Wingate’s Raiders”), who fought as light infantry during the Central Burma campaign in World War II. “They were loaded with huge 34-kg packs and marched unmercifully through man-killing terrain.”[20] These soldiers performed a 225-km road march just before their deployment to Burma. Units within the US Army’s 10th Mountain Division routinely road marched with their fighting loads about three times per month. Training guidance prescribed a quarterly road march of 40 km (7 min/km [or 11 min/mile] pace) and a yearly road march of 161 km in 5 days.[21]

Body Stature and Body Mass as Factors in Load Carriage

A service member’s height and weight might be important factors in load carriage.[2,22] Larger service members might be able to carry heavier loads by virtue of their greater bone and muscle mass.[23–25] It has been estimated that humans have increased their height about 10 cm since the Industrial Revolution, possibly because of better nutrition.[26] Table 3 provides a summary of the heights and weights of various groups derived from a variety of sources. Before the British Crimean War, only minimum standards were available. US samples show a progressive increase in height, weight, and body mass index since the American Civil War. The increase in weight is apparently attributable to an increase in fat-free mass, with temporal changes in body fat less consistent. Data on the general US population suggest that body weight and body mass index have been progressively increasing since 1980.[27,28] Data on Army recruits suggest that the increase in weight is accounted for by about equal increases in fat-free mass and body fat.[29]

Physiological and Biomechanical Aspects of Load Carriage

Although historical studies are useful to show that the problems of load carriage have been with the military for a considerable time, it is physiological and biomechanical research conducted during the last 70 years that have developed some practical methods to reduce load stress on service members. Many general principles and techniques have emerged, but studies do not reveal a single way of carrying loads that applies to all situations. Commanders must consider the mission, environment, time, and terrain to adjust the service members' burdens.

Load Distribution

There are many ways to carry loads, and the technique used depends on the characteristics of the load (size, shape, mass, etc), how far the load may be carried, previous experience, and the equipment available to the service member.[30] Figure 5 illustrates techniques of carrying loads that have been directly investigated for individual soldiers.[30–37] Team-lifting techniques can assist in moving larger loads, as shown in Figures 6 and 7.

Two load-carrying systems currently available to individual US soldiers include (1) the All-Purpose Lightweight Individual-Carrying Equipment (ALICE) pack and (2) the Modular Lightweight Load-Carrying

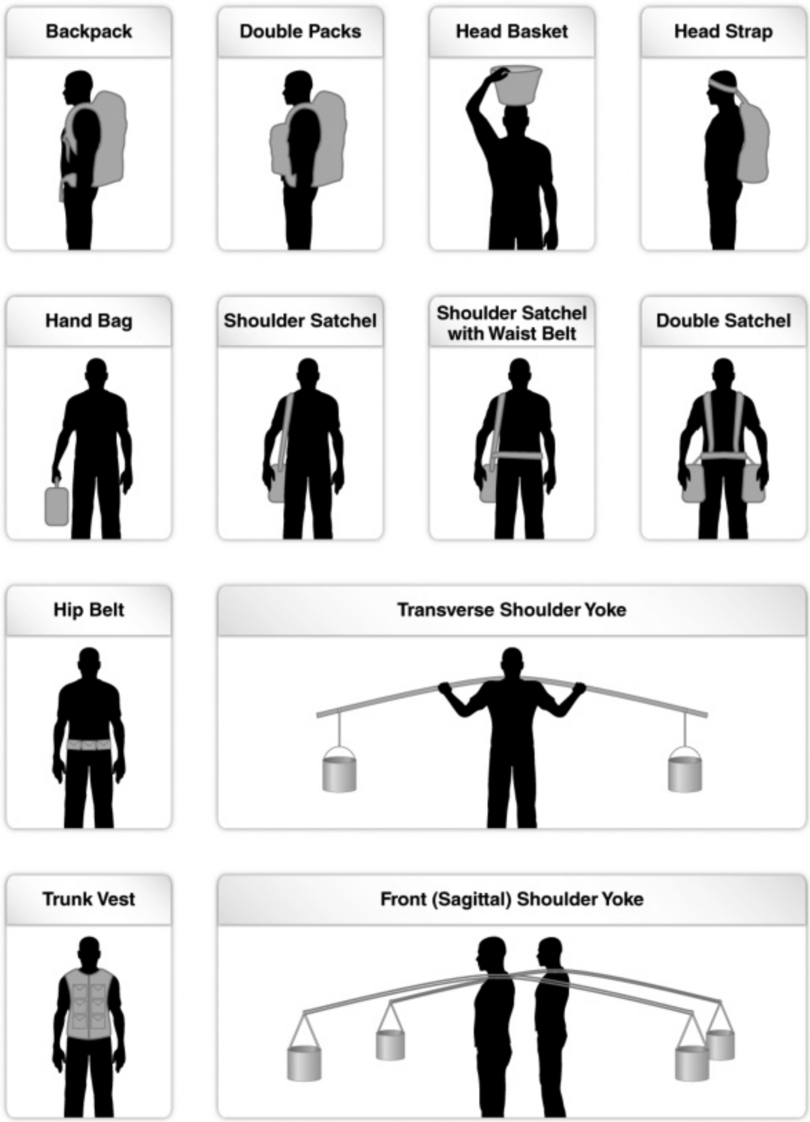

Figure 5. *Methods of load carriage investigated in various studies.*
Photograph: Courtesy of SURVIAC (Survivability/Vulnerabiity Information Analysis Center; Wright-Patterson Air Force Base, Ohio)/ARL (US Army Research Laboratory; Adelphi, Md)/ Booz Allen (McLean, Va).

Figure 6. *An Army relief team carries an Army tent in a box to a waiting truck following a major earthquake on November 23, 1980. The men are from the 1st Battalion, 509th Infantry Regiment, Vicenza, Italy.*
Photograph: Courtesy of DefenseImagery.mil. From http://www.defenseimagery.mil/imagery.html#a=search&s=4%20man%20carry&chk=6cfe0&guid=beed46698d7727f882c43439bd8bcef71d23261e.

Equipment (MOLLE) pack. The ALICE pack is more than 35 years old, having been introduced within the 1973 to 1974 time frame. The ALICE pack is durable, stable with heavy loads, and provides ventilation to the back because the external frame holds the rucksack away from the body; however, adjustment is limited. Studies completed in 1995[38] showed the need for a modular system, with better equipment compatibility and features for fitting special equipment. Studies[39] resulted in the development and improvement of the MOLLE pack, which was adopted by the Marine Corps in 1999 and by the Army in 2001.[40] The MOLLE pack (Figure 8) is an entire system that consists of a main pack with an external frame, butt pack, and load-bearing vest. The main pack has pouches and a sleeping bag compartment attached to the external frame. The external frame is a lightweight plastic polymer that is anatomically contoured. A patrol pack can be detached and used separately. The vest has removable pockets to accommodate different objects. Padded shoulder straps, waist belt, and strap adjustments allow for better load distribution, and

Figure 7. *Marines carry a stretcher bearing a sniper victim on Guadalcanal in World War II. Photograph: Courtesy of the National Archives and Records Administration, Archival Research Catalog. From: http://www.pbs.org/thewar/at_war_timeline_1942.htm.*

the soldier can shift the load to different anatomical locations. An intermediate system between the ALICE pack and the MOLLE pack was the Integrated Individual Fighting System that was introduced in 1988. The Integrated Individual Fighting System had a large internal frame pack and a tactical load vest, with pockets that allowed more flexibility than the ALICE system; however, the internal frame pack was unstable with heavy loads (more than 36 kg) and was prone to breakage.[40,41]

Figure 8. *Soldier wearing the Modular Lightweight Load-Carrying Equipment (MOLLE) pack. The MOLLE pack is an entire modular system that includes a main pack with an external frame, butt pack, and load-bearing vest. A patrol pack can be detached and used separately. The vest has removable pockets to accommodate different objects. Padded shoulder straps, waist belt, and strap adjustments allow for better load distribution, and the soldier can shift the load to different anatomical locations.*
Photograph: Courtesy of Wikipedia.org. From https://peosoldier.army.mil/factsheets/SEQ_CIE_MOLLE.pdf.

Backpacks and Double Packs

Where the load is carried on the body will affect both energy cost and gait mechanics. Loads can be transported with the lowest energy cost (ie, most efficiently) when they are carried on the head.[35,42] However, this method is impractical for military operations because it requires a long training time to learn how to use effectively, is useful only on unobstructed horizontal terrain, and produces a high profile (greater body signature). A more practical choice is to carry a load as close as possible to the center of mass of the body.[43–45] In this regard, the backpack and double pack methods (Figure 9) have been shown to have a lower energy cost than most other forms of load carriage.[36,37,46,47] Nonetheless, a backpack places most of the load on the back and produces a forward inclination of the trunk and head that becomes greater as the load increases.[48–51] The forward inclination keeps the load-plus-body center of mass over the feet (the base of support), but this leads to repetitive contractions (and stress) of low back muscles.[52,53] Just standing with a backpack increases postural sway (anterior-posterior, medial-lateral center of pressure excursions) in a linear manner as the load increases.[54] On the other hand,

Figure 9. *A Marine with a double pack at a forward operating base. The marine is from the 26th Marine Expeditionary Unit and is boarding for a flight back to Kandahar, Afghanistan, in support of Operation Enduring Freedom.*
Photograph: Courtesy of DefenseImagery.mil. From http://www.defenseimagery.mil. VIRIN: 020212-M-7370C-126. Photographer: CWO2 William D. Crow, USMC.

the double pack produces fewer deviations from normal walking than does a backpack, including less forward lean of the trunk.[49,55] With the double pack, increasing load produces a reduction in stride length and an increase in stride frequency that is more desirable because it can reduce stress on the bones of the foot. In contrast, stride length becomes longer as backpack loads increase which, by the same line of reasoning, could be potentially harmful.[30]

Double packs can be useful in some military situations (eg, medics carrying their aid bags on the front of their bodies), but backpacks appear to provide greater versatility in military situations. Double packs can inhibit movement and limit the field of vision in front of the body, making it difficult to see obstructions and traps. They can be burdensome to don and doff; doffing can be very important when sudden or unexpected enemy contact occurs. The double pack can also induce ventilatory impairments[30] and greater heat stress symptoms,[56] compared with the backpack. The double pack can restrict tasks, such as firing weapons and donning protective masks.

Service members can take advantage of what has been learned from the double pack by distributing the load more evenly over the torso. Although it is difficult to make the load equal on the front and back of the body, both the ALICE and MOLLE systems allow a part of the load to be moved forward onto the load-carrying vest. Doing this might be expected to reduce energy cost, improve body posture, and reduce injuries.

Pack Frames and Hip Belts

Pack frames and hip belts reduce shoulder stress. The shoulder straps of a pack exert pressure on the skin, which can be measured with transducers under the straps.[57] Shoulder pressure is considerably lower with a pack frame incorporating a wide hip belt, compared with a pack frame without a hip belt. In one study, 10 kg carried in a frameless pack resulted in a peak pressure of 203 mm Hg; the same mass carried in a pack with a frame and wide hip belt resulted in a peak pressure of only 15 mm Hg. The pack with the frame and hip belt produced less electromyographic activity in the trapezius muscle, also suggesting less stress in the shoulder area.[57]

When a pack frame and hip belt are used for a load between 14 to 41 kg, the proportion of the load supported on the hips and lower back is 30% and the load on the shoulders is 70%, regardless of the load mass. There is a consistent anterior force exerted on the lower back that might increase stress in this area.[58] There is some suggestion that experienced individuals adjust their walking posture to reduce forces and force fluctuations in the shoulder straps.[59] Rigid rods attached to both sides of the pack and extending into the hip belt transfer about 14% of the vertical load from the upper torso to the pelvis.[60]

Internal frame packs have supporting structures (metal and plastic) inside the fabric of the pack and keep the pack closer to the center of mass of the body. External frame packs have the supporting structure on the outside of the pack, and the pack is usually farther away from the center of mass of the body. There is conflicting information regarding whether the internal frame pack has a lower energy cost than the external frame pack.[61,62] There is no difference in perceived exertion between external and internal frame packs when walking on level, even terrain.[61] However, perceived exertion over rough terrain is lower with the internal frame pack.[63]

Subjective reports of discomfort vary, depending on the design of the pack system. For backpacks with and without frames, the majority of discomfort appears to be in the neck and shoulder region, although foot discomfort can also be substantial, presumably because of the development of hot spots and blisters.[64,65] For a backpack with a hip belt, discomfort is localized to the midtrunk and upper legs.[66] Overall, when a portion of the load is carried on the waist through use of a hip belt, there is less subjective discomfort than there is with shoulder load carriage.[67] When walking uphill, individuals give higher ratings for balance and ease of gait for packs with hip belts that pivot in the sagittal plane.[68]

Placement of Load in the Backpack

The location of load in the backpack can affect energy cost, subjective comfort, and body mechanics. Using both internal and external frame packs, higher energy costs were associated with a load that was lower in the pack and farther away from the body; lower energy costs were associated with loads placed higher in the pack and closer to the body (Figure 10).[69,70] However, another study using an external frame pack and similar methodology found no difference in energy cost with load placements.[71] A more even distribution of loads using a rack system within the pack resulted in considerably lower ratings of discomfort in the neck, shoulders, and lower back.[63]

Although both high- and low-load placements bring about forward body lean (knees, hips, shoulders, and head are farther forward), this effect is greater for low placements. This is because the lower load is closer to the ankles, which requires more forward body rotation to bring the

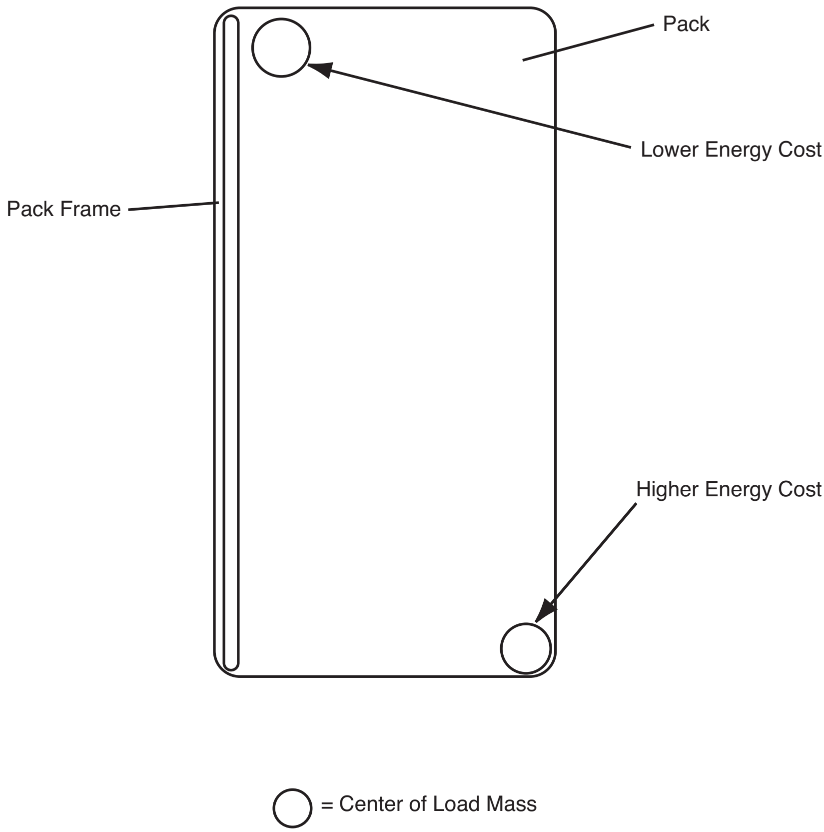

Figure 10. *Effects of load distribution within the pack on energy cost. A high and more anterior load results in a lower energy cost than a low and more posterior load.*
Data source: Obusek JP, Harman EA, Frykman PN, Palmer CJ, Bills RK. The relationship of backpack center of mass to the metabolic cost of load carriage. Med Sci Sports Exerc. 1997;29:S205.

pack center of mass over the feet.[72] The additional forward body rotation tends to bring the body's center of mass over the front half of the foot, which could increase the likelihood of foot strain and injury.

Nonetheless, placement of the load high in the pack tends to destabilize posture to a greater extent than lower placements, especially among tall men, as measured by the amount of body sway while standing with the load.[73] Dynamic moments are about 40% greater with high-back placement, an affect attributed to the greater rotational inertia of the high load.[74]

A low- or midback load placement might be preferable for stability on uneven terrain, particularly during unexpected stumbles, when high-load placement can necessitate relatively high-muscle forces to maintain postural stability. The high-load placement might be best for even terrain because it keeps body posture with a load most similar to that without a load.[72]

Strap Adjustments

Although not tested experimentally, it is reasonable to assume that shifting loads from one part of the body to another during a march can improve soldier comfort and allow loads to be carried for longer periods of time. Load shifting is accomplished with some pack systems using various strap adjustments. Strap adjustments can redistribute the load to other muscles or other portions of previously loaded muscles. Portions of the body subjected to high-load pressures for long periods of time can suffer discomfort, circulatory occlusion, and paresthesis.[30,67,75]

Some rucksacks have sternum straps that are attached horizontally across both shoulder straps at midchest level. When the sternum strap is tightened, it pulls the shoulder straps toward the midline of the body so that pressure is shifted more medially. When the sternum strap is loosened, the shoulder straps move laterally, and the load is also shifted laterally.

Most pack systems with hip belts and shoulder straps have adjustments that presumably allow more of the load to be placed on the hips or shoulders. When the shoulder strap tension is reduced (straps loosened), more of the load is placed on the hips. With the shoulder straps tighter, more of the load is placed on the shoulders.

Some pack systems have load-lifter straps that attach the top of the shoulder straps to the pack frame. When the strap is tightened, the top of the load is pulled more anteriorly over the base of support; however, when the strap is loosened, the top of the load falls more posteriorly. Other strap adjustments that shift load pressures, center the pack, and improve lumbar support can further improve soldier mobility and comfort.[68]

Load Carriage on the Feet, Thighs, and in the Hands

Loads can be carried in places other than the torso, although other body positions result in higher energy expenditure. Loads carried on the feet result in an energy cost five to seven times higher than an equivalent load carried on the upper body.[44,76,77] The increase in energy expenditure is 7% to 10% for each kilogram added to the foot.[44,76–79] This finding suggests that footwear should be as light as possible, compatible with durability requirements.

Loads carried on the thigh result in energy costs that are lower than foot carriage, but greater than torso carriage. For each kilogram added to the thighs (at about midthigh level), the increase in energy cost is about 4%.[80,81] When load masses are carried on the thighs (compared with the feet), less mechanical work is performed because of reduced inertia of the body segments; therefore, changes in gait with increasing thigh load are minimal.[80]

Carriage of loads in the hands also results in a higher energy cost than with torso carriage[36,46,76] and produces greater cardiovascular strain.[82] Hand carriage is more efficient than foot carriage because the energy cost of carrying loads on the ankles exceeds that of carrying loads in the hands by five to six times if the hand load is carried close to the body.[44] This is likely related to the fact that leg swing is an essential part of walking, whereas arm swing is a secondary aspect of gait that can be greatly reduced without affecting walking speed. For hand carriage tasks (eg, transporting a stretcher), the use of simple shoulder straps or more complex harness systems considerably reduce cardiovascular stress and result in more subjective comfort.[83,84]

Rifle Carriage

A rifle will almost always be carried in dismounted military training and operations. Rifle carriage restricts arm swing, adds weight, and moves the center of mass more anteriorly. During rapid walking (5.4 km/h), a 4.4-kg rifle (a loaded M16A2 weighs 4.0 kg) has minimal, but significant, effects on human gait. There are increases in forces produced at heel strike (ground impact forces, about 5%), forces to decelerate the body (maximum breaking forces, about 1%), and side-to-side forces (mediolateral impulse, about 12%). Many of these changes are less because of the mass of the rifle and are more associated with the restriction of arm movement, which increases the movement of the body center of mass.[85,86]

Body Armor

Individual body armor is commonly worn by soldiers to protect against small arms fire and explosive devices. The system currently used is the Interceptor Multipurpose Body Armor System, consisting of two major components: (1) an outer tactical vest (OTV) and (2) small arms protective inserts. The OTV is composed of a Kevlar weave and provides protection from 9-mm bullets and fragmentation. The OTV has a removable collar, throat protector, and groin protector. The small arms protective inserts are silicon carbide/boron carbide plates worn in the front and back of the OTV, and provide protection from rifle and machine gun fire. Studies[87, 88] indicated that additional protection was needed and subsequently developed enhancements included deltoid and axillary protectors providing fragmentation and projectile protection over and under the arms (Figure 11). A medium-sized vest without deltoid and axillary protectors and other vest attachments weighs about 13 kg.[89,90]

As might be expected, the wearing of body armor (compared with no body armor) increases perceived exertion, the energy cost of walking, vertical ground reaction forces, and loading rate (change in force over time from heel strike to peak impact force)[91,92]; men and women respond in a similar manner.[93] As walking velocity increases, the increase in energy cost and relative exercise intensity (%$\dot{V}O_{2max}$) is not linear, but rather the increase is exponential.[92] A vest increases heat stress (core temperature, body heat storage) during prolonged (2–4 hours) walking, independent of the increase in energy cost, and a spacer garment (to presumably provide "passive cooling") does not mitigate this heat

Figure 11. (*Left*) *Interceptor Multipurpose Body Armor System with removable collar, throat protector, and groin protector.* (*Center*) *Deltoid and* (*right*) *axillary protectors, respectively. Photographs: Courtesy of GlobalSecurity.org. From http://www.globalsecurity.org/military/systems/ground/interceptor.htm.*

stress.[94] Soldiers returning from deployment report deployment-related increases in musculoskeletal pain, with 24%, 29%, and 27% of soldiers attributing neck, back, and upper extremity pain, respectively, to the wearing of individual body armor.[89]

Load Carriage Using Carts and Motorized Vehicles

Military personnel seldom consider using wheeled carts to transport loads, but, for some missions, this can be an option. In a field trial of three manually operated load carts, both positive and negative aspects emerged. On the positive side, the tested carts were generally durable; able to carry or exceed their rated loads (91–181 kg); and were effectively used on flat terrain, in barrier construction, and in resupply. On the negative side, the carts created problems on rugged terrain: they were noisy in brush or rocky areas, thus reducing tactical surprise; and equipment could get caught in the wheels of some carts.[95]

A combat load cart appropriate for military operations should have a low center of gravity, a wide wheel base, and a large wheel size.[96,97] Compared with body carriage, energy cost was reduced by 88% when a 50-kg load was pushed in a cart on a smooth surface.[97] Pulled carts (rather than pushed) seem to be easier to control on uneven terrain and also result in considerable energy cost-savings.[96] Over mixed terrain (paved road, dirt road, field, and rough trail), a cart pulled by a hip belt resulted in 54% faster march times (compared with a rucksack) over a 3.2-km distance.[98] This latter cart, specifically developed for military operations, is available.

Besides carts, removing much of the load burden from the soldier can be achieved through the use of a wide variety of motorized vehicles. Systems that have carried soldier equipment in rugged areas in Afghanistan have included the Military Gator (or M-Gator; John Deere Company, Moline, Ill) and the Polaris Sportsman Military Vehicle (Polaris Industries, Inc, Medina, Minn). The Military Gator is a two-seat, six-wheel squad vehicle that can carry up to a 550-kg load and runs on JP8 fuel (Figures 12 and 13). The Polaris Sportsman Military Vehicle is a four-wheel, all-terrain vehicle that can carry one person and a load up to 204.1 kg (Figure 14).[99,100] Of course, there will still be terrain that will not be suitable for carts or motorized vehicles of any type, and soldiers will be personally required to bear the load.[5]

Figure 12. *The Military Gator. This is a two-seat, six-wheel squad vehicle that can carry up to a 550-kg load and runs on JP8 fuel.*
Photograph: Courtesy of Olive-Drab.com. From http://www.olive-drab.com/idphoto/id_photos_m-gator.php.

Physiological Factors Associated With Load Carriage

Several studies have examined associations between load carriage and various physiological factors using very similar methods. Subjects were administered a series of physiological tests to measure physical characteristics, body composition, muscular strength, anaerobic capacity, and aerobic capacity. Subjects were asked to complete a given distance as rapidly as possible while carrying various load masses. Trip completion times were correlated with these physiological measures.

Using univariate correlations, early studies demonstrated low ($r = 0.2$–0.6), but statistically significant, relationships between trip completion times and aerobic capacity, back and lower body strength, and fat-free mass.[23,101,102] More recent studies using multivariate techniques generally confirm that aerobic fitness, fat-free mass, and leg/back strength are important physiological factors associated with load carriage performance and changes in load carriage performance.[24,25] These studies provide clues as to the components of physical fitness that should be trained to improve load carriage performance.

Figure 13. *US Army soldiers assigned to the 86th Combat Support Hospital using a Military Gator to transport a litter patient at an undisclosed location in Iraq, in support of Operation Iraqi Freedom.*
Photograph: Courtesy of DefenseImagery.mil. From http://www.defenseimagery.mil. ID: DF-SD-04-01753. Photographer: SSGT Quinton T. Burris, US Air Force.

Physical Training and Load Carriage

Appropriately designed physical training can improve service members' load carriage capabilities. Walking with backpack loads over several weeks results in a decrease in the energy cost of carrying the load.[103] Australian military recruits with high initial aerobic capacity (predicted $\dot{V}O_{2max}$ = 51 • mL • kg^{-1} • min^{-1}) further improved their aerobic fitness by engaging in regular backpack load carriage. Loads were progressively increased during the 11-week basic training program, and improvements in aerobic capacity were similar to those of a control group performing the traditional recruit training program involving running.[104]

Twelve-week physical training programs involving a combination of aerobic training (running) and resistance training improved the speed at which men completed a 3.2-km distance carrying 46 kg,[105] and women completed a 5-km distance carrying 19 kg,[106] even when these load carriage tasks were not included in the training program. It is interesting that

Figure 14. *Polaris Sportsman military vehicle. It is a four-wheel, all-terrain vehicle that can carry one person and a load up to 204 kg.*
Photograph: Courtesy of Justin Burke, Marketing Manager, Polaris Defense, Medina, Minn. From http://www.polarisindustries.com.

neither running nor resistance training alone improved march speed,[105] suggesting that both aerobic capacity and muscle strength must be trained to improve road marching capability. When regular road marching with loads (at least twice a month) was included in a training program that also involved running and resistance training, service members marched faster than if march training was not included.[107] Substantial improvements in load-carrying performance were found when civilian women were trained with a combination of resistance training, running, and load-carrying.[108]

Gender Differences

Compared with men, women walk with shorter stride length and greater stride frequency. As loads increase, women's stride length decreases, whereas men's stride length does not show significant change. With increasing load, women also show a more pronounced linear increase in the time that both feet are on the ground (double support time) than do men. To bring the center of the load mass over the feet (base of support), women tend to hyperextend their necks and bring their shoulders farther forward than do men, possibly to compensate for less upper body strength. Many of these differences between men and women persist even when differences in body size and composition are taken into account.[40,50]

When men and women were asked to complete a 10-km road march as quickly as possible carrying loads of 18 kg, 27 kg, and 36 kg (using ALICE packs), men were about 21% faster, regardless of load. On systematically administered questionnaires, women commented more often than men that the pack straps were uncomfortable, that the pistol belts fit poorly, and that the rucksacks (ALICE packs) were unstable. An independent predictor of march time (when gender was included in the equation) was acromial breadth (shoulder breadth). Because pack systems have been designed primarily based on the anthropometry of men, these data suggest that pack systems designed considering the anthropometry of women can lessen the time gap between men and women.[109] Studies with the MOLLE pack suggest that the well-padded hip belt allows a better transfer of the load to the hips so that women can use the stronger muscles of the legs to carry the load.[40,58] This might assist in improving female load carriage performance.

Predicting the Energy Cost of Carrying Military Loads

Studies conducted on treadmills for short periods of time show that energy cost increases in a systematic manner, with increases in body mass, load mass, velocity, grade, or a combination of these items.[110–116] Type of terrain also influences energy cost, as shown in Figure 15.[96,117,118] Pandolf and colleagues[119] expanded on the work of Givoni and Goldman[120] to develop an equation (1) to predict the energy cost of load carriage:

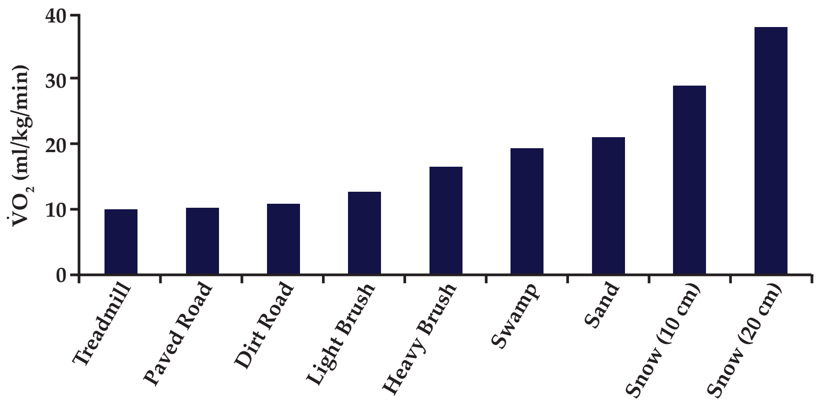

Figure 15. *Effects of terrain on energy cost. Energy cost increases about 8% on a dirt road and about 24% for moving through light brush. Much heavier brush requiring the use of arms and more lifting of the legs to move over downed trees and brush can increase energy cost by 60%. Going through swampy land or walking on sand almost doubles energy cost. Walking in snow without the use of snowshoes can considerably increase energy cost 3 or 4 times, depending on the depth and quality of the snow. This increase in energy cost with deeper snow is presumably because of the extra energy needed to raise the legs. Numbers after the snow estimates are the depth of depression the shoe makes in the snow.*
Data sources: Haisman MF, Goldman RF. Effect of terrain on the energy cost of walking with back loads and handcart loads. J Appl Physiol. 1974;36:545–548. Pandolf KB, Haisman MF, Goldman RF. Metabolic energy expenditure and terrain coefficients for walking on snow. Ergonomics. 1976;19:683–690. Soule RG, Goldman RF. Terrain coefficients for energy cost prediction. J Appl Physiol. 1972;32:706–708.

$$M_w = 1.5 \bullet W + 2.0 \bullet (W + L) \bullet (L/W)^2 + T \bullet (W + L) \bullet (1.5 \bullet V^2 + 0.35 \bullet V \bullet G), \tag{1}$$

where M_w = metabolic cost of walking (Watts), W = body mass (kg), L = load mass (kg), T = terrain factor (1.0 = blacktop road, 1.1 = dirt road, 1.2 = light brush, 1.5 = heavy brush, 1.8 = swampy bog, 2.1 = loose sand, snow [dependent on depth of depression {$T = 1.30 + 0.082 \bullet D$, where D = depression depth in centimeters}]),[117] V = velocity or walk rate (m/sec), and G = slope or grade (%).

The Pandolf equation has been independently validated using a range of loads and body masses.[121] However, the equation has several limitations. First, it does not predict accurately the energy cost of downhill walking.[122,123] Downhill walking energy cost approximates a U-shape when plotted against grade: it initially decreases, then begins to increase.[124–126] The lowest energy cost occurs between –5% to –15%, depending on individual gait characteristics.[124,126] Santee and colleagues[126] developed an empirical model to predict the energy cost of downhill walking. The model assumes that the initial reduction in downhill walking energy cost is from the negative work of gravity, but that this is reduced by the eccentric action of the muscles to decelerate the body and energy absorbed by the muscles and joints. Equation (2) is as follows:

$$(2) \qquad W_{td} = W_l + (2.4\,(m_t \bullet g \bullet h \bullet s^{-1}) \bullet 0.3^{(\alpha/7.65)}),$$

where W_{td} = total metabolic cost (Watts), W_l = metabolic cost of level walking (Watts), m_t = total load mass (kg), g = acceleration caused by gravity (9.8 m/s^2), and α = grade or slope for negative work.

A second limitation of the Pandolf equation might be that it does not account for increases in energy cost over time. In studies used to develop the equation, energy cost was examined for short periods, usually less than 30 minutes. Most studies[127–129] have shown that the energy cost of prolonged (≥2 h) load carriage at a constant speed increased over time at higher loads, or speeds or both. Energy cost also increases over time during downhill walking with loads.[129] Whether or not energy expenditure increases over time is important, because the individual carrying the load might become more easily fatigued if energy cost does increase.

Medical Problems Associated With Load Carriage

Injuries associated with load carriage, although generally minor, can adversely affect an individual's mobility and thus reduce the effectiveness of an entire unit. Tables 4 and 5 show the results of two studies that recorded acute injuries during military road marching operations.[130,131] Foot blisters, back problems, and metatarsalgia were the most common march-related injuries. These injuries are similar to those self-reported by recreational hikers who generally carry lighter loads, but the relative frequency is somewhat different.[132–134] Table 6 summarizes common load carriage-related injuries, as well as prevention and treatment strategies.

Foot Blisters

Foot blisters are the most common load-carriage-related injury[65,131,135–137] (Figure 16). They result from friction between the socks and skin,[138–140] a product of point pressures exerted by the boot and the foot. Blisters can cause extreme discomfort, prevent service members from completing marches, and can lead to many days of limited activity.[131,141,142] If they are not properly managed, especially in field conditions, they can progress to more serious problems, such as cellulitis or sepsis.[141,143]

Table 4. *Injuries Among 355 Infantry Soldiers During a 20-km Maximal Effort Road March*[131]

Injury	During March*: Soldier Continued March (n)	During March*: Soldier Did Not Continue March (n)	1–12 Days Post-march (n)†	Totals: N	Totals: %
Foot blisters	16	0	19	35	38
Back pain/strain	5	7	9	21	23
Metatarsalgia	1	1	9	11	12
Leg strain/pain	0	0	7	7	8
Sprains	1	1	4	6	7
Knee pain	0	0	4	4	4
Foot contusion	0	1	1	2	2
Other	1	2	2	5	5
Total	**24**	**12**	**55**	**91**	**100**

*From medics and physician during the march.
†From medical records after the march.

Heavy loads increase blister incidence,[109,137,144] possibly by increasing pressure on the skin and causing more movement of the foot inside the boot through higher propulsive and breaking forces.[49,145] Rifle carriage alone has minor effects on maximal breaking and propulsive forces.[85] Other blister risk factors include tobacco use, low aerobic fitness, and ethnicity other than black.[130,146]

When loads are very heavy (>61 kg), the double pack has been shown to demonstrate a lower blister incidence than the backpack,[147] suggesting

Table 5. *Injuries Among 218 Infantry Soldiers During a 5-Day, 161-km Road March*[130]

Injury	During March*: Soldier Continued March (n)	During March*: Soldier Did Not Continue March (n)	1–15 Days Post-march (n)†	Totals: N	Totals: %
Foot blisters	43	3	3	49	48
Metatarsalgia	8	2	9	19	19
Back pain/strain	4	1	1	6	6
Sprains	2	3	0	5	5
Knee pain	3	1	3	7	7
Ingrown toenail	0	3	0	3	3
Stress fracture	0	1	0	1	1
Other	8	3	1	12	12
Total	**68**	**17**	**17**	**102**	**100**

*From physician's assistants at fixed medical sites along the march.
†From medical records after the march.

Table 6. *Summary of Common Load Carriage-Related Injuries With Prevention and Treatment Strategies*[*140,177]

Injury	Signs and Symptoms	Prevention	Treatment
Foot blisters	Elevated area, lighter in color than surrounding skin, and filled with fluid; pain, burning, warmth, and erythema	1. Use acrylic, nylon, or polyester inner sock; use thick, snug, dense-weave outer sock with inner sock 2. Use Spenco[†] insoles 3. Utilize antiperspirants 4. Make sure that load distribution is more evenly around the body center of mass 5. Reduce load mass 6. Precondition feet through physical training and road march practice 7. Improve aerobic fitness 8. Cease smoking/tobacco use 9. Cover skin when hot spots appear	Intact blister: drain, leave top in place, and use light pressure dressing Torn blister: remove top, use antibiotic ointment, and put on surgical bandage Use hydrogel or hydrocolloid dressings; also polyurethane films
Metatarsalgia	Pain, swelling on sole of foot	1. Precondition feet through physical training and road march practice 2. Reduce load mass	RICE[‡] Antiinflammatory medication[§]
Stress fractures	Persistent, bony pain; well-circumscribed palpable area of bony tenderness	1. Cease smoking/tobacco use 2. Precondition feet and legs through physical training and road march practice	RICE Antiinflammatory medication
Knee pain	Pain, swelling, crepitus, and instability	1. Perform lower extremity strengthening and stretching	RICE Antiinflammatory medication
Low-back pain	Pain, muscle spasm, and neurological symptoms	1. Be sure that load distribution is more evenly around the body center of mass 2. Reduce load mass 3. Perform trunk and abdominal strengthening	RICE Antiinflammatory medication
Rucksack palsy	Upper extremity numbness, paralysis, and cramping; scapular winging	1. Use framed rucksack 2. Utilize hip belt on rucksack 3. Employ load shifting via strap adjustments	RICE Antiinflammatory medication
Meralgia paresthetica	Pain, paresthesia, and weakness in the anterolateral thigh	1. Use properly fitted body armor 2. Avoid compressing thighs with lower edge of body armor	Reduce body armor wear Antiinflammatory medication

*See text for full descriptions and applications.
†Spenco Medical Corporation, Inc, Waco, Tex.
‡RICE: Rest, Ice, Compression, Elevation
§Antiinflammatory medication refers to aspirin or a nonsteroidal antiinflammatory drug.

that better load distribution can reduce blisters. Spenco shoe insoles (Spenco Medical Corporation, Inc, Waco, Tex) have also been shown to reduce foot blister incidence, possibly because they absorb frictional forces in anteroposterior and mediolateral directions.[148–150] Regular physical training with load carriage induces skin adaptations that reduce the probability of blisters.[140] Thus, blisters can be less of a problem in units that march regularly; however, sudden increases in march intensity or distance will probably make blisters more likely, regardless of training regularity.

Moist skin increases frictional forces and probably increases blister incidence.[140,141,151] Acrylic socks decrease the number and size of blisters,[152] possibly by conducting sweat away from the foot.[153] A nylon sock worn inside a wool sock reduces the incidence of blisters on soldiers who are road marching.[154,155] Polyester socks alone, or a thin polyester sock worn inside thicker socks (that are either wool-polypropylene or other such moisture-wicking wool blend materials), reduce foot blister incidence during military training.[156,157]

Figure 16. *Friction blisters on the foot.*
Photograph: Courtesy of Wikimedia Commons. From http://commons.wikimedia.org/wiki/File:Friction_Blisters_On_Human_Foot.jpg.

Antiperspirants also reduce foot sweating,[158,159] and some anecdotal reports and case studies suggest they might be effective in reducing blisters.[160–162] A 20% solution of aluminum chloride hexahydrate in an anhydrous ethyl alcohol base (eg, Drysol, Person & Covey, Inc, Glendale, Calif) was effective in reducing the likelihood of march-related blisters when the preparation was applied to the entire foot for at least three nights before a march.[163] Once the antiperspirant effect has been achieved, it can be maintained with applications once per week.[164] However, many individuals report irritant dermatitis using this preparation,[163] which can require the application of a topical steroid. Other options in this case include using a lower concentration preparation (eg, Xerex, Person & Covey, Inc, Glendale, Calif), changing the treatment schedule (using the same number of applications, but over a longer period of time), or discontinuing use. Antiperspirants in emollient bases are not effective in reducing blisters, presumably because emollients interfere with the antiperspirant effect.[165]

Soldiers typically experience areas of friction known as "hot spots," the subjective experience of which is a localized warm or burning sensation. This presumably preblister stage is characterized as a local red (erythema) and tender area (Figure 17). When hot spots are detected, blisters may be avoided by shielding the affected area with a low-friction skin covering. Various skin coverings have been examined for their coefficients of friction (μ), and lower μ values may be more effective in reducing blister incidence. Tested skin coverings (with μ values in brackets) include the following:

- Bursatec (Bursatec, Mexico City, Mexico) [0.57],
- Dr. Scholl's Moleskin Plus (Schering-Plough HealthCare Products, Inc, Memphis, Tenn) [0.69],
- Moleskin [0.94],
- Band-Aid Brand Adhesive Bandages (Johnson & Johnson Consumer Companies, Inc, New Brunswick, NJ) [1.01],
- Band-Aid Plastic Bandages [1.03],
- Spenco 2nd Skin Blister Pad [1.04],
- New-Skin (Prestige Brands, Inc, Irvington, NY) [1.05],
- Nexcare Comfort Bandage (3M Company, St Paul, Minn) [1.08],
- Dr. Scholl's Blister Treatment [1.20],
- Band-Aid Blister Block [1.37], and
- Tegaderm (3M Company, St Paul, Minn) [1.54].[166]

Figure 17. *A "hot spot" on the medial aspect of a soldier's foot during a road march.*

Another option is a doughnut pad or covering (eg, DuoDERM, ConvaTec, Inc, Skillman, NJ), which should be applied to reduce friction and possible blister development.[167]

There are few studies of blister treatment, and care is based on clinical experience and common sense. Small blisters (<5 mm) are usually self-limiting and should not be drained unless they are painful, because of the risk of infection.[168] A small, doughnut-shaped moleskin pad can be placed over the blister to prevent rupture. If the blister is larger than 5 mm and on a weight-bearing area, it should be drained. To promote blister-top adhesion and healing, blister drainage should occur at the proper time. For blisters less than 24 hours old, several punctures should be made with a sterile needle or a no. 11 surgical blade (Figure 18). For older blisters,

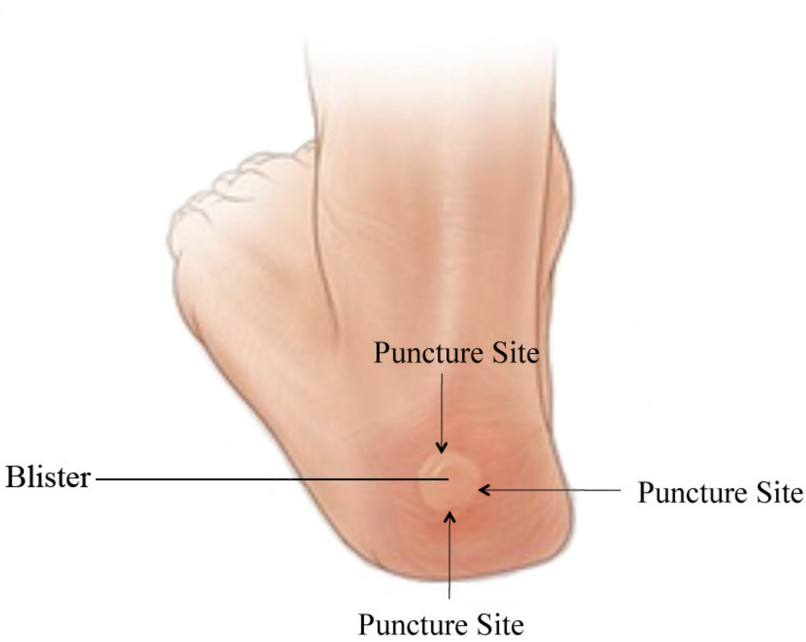

Figure 18. *Friction blisters showing suggested puncture sites to drain the blister. For blisters less than 24 hours old, several punctures should be made with a sterile needle or a no. 11 surgical blade. Illustration: Courtesy of Heidi Moncrief, Healthwise, Inc, Boise, Idaho. From http://64.143.176.9/library/healthguide/en-us/images/media/medical/hw/hwkb17_072.jpg.*

a single puncture is recommended.[169] Tops should be kept in place to serve as functional dressings.[170] A pressure dressing (eg, gauze pad and adhesive tape) can be applied to ensure that the blister roof adheres to the underlying tissue. If the top of the blister is almost completely torn off, it should be removed[171] and the site treated as an open wound. In addition to antiseptic treatments (eg, antibiotic ointment), a surgical bandage should be applied.[169] For smaller blisters, a doughnut-shaped moleskin pad affixed with a porous adhesive knit cover (eg, Coverlet, BSN-Jobst, Charlotte, NC) will protect the blister as shown in Figure 19; for larger blisters, a larger dressing will be needed.[162,164] Hydrogel dressings (Figure 20) (eg, Spenco 2nd Skin) or polyurethane films (eg, Tegaderm) can be affixed to the blister and covered with a pad and tape.[169,172] Hydrocolloid dressings, such as DuoDERM (ConvaTec, Inc), can also be helpful in allowing mobility[173] and promoting healing.[172,174,175]

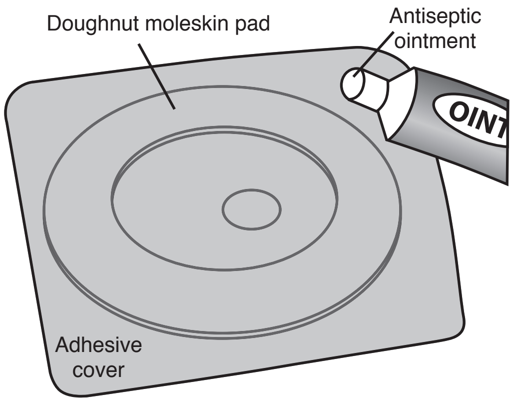

Figure 19. *Treatment for smaller blisters. A doughnut-shaped moleskin pad affixed with a porous adhesive cover (eg, Coverlet, BSN-Jobst, Charlotte, NC) will protect the blister. Illustration: Courtesy of the US Army Research Institute of Environmental Medicine (Natick, Mass).*

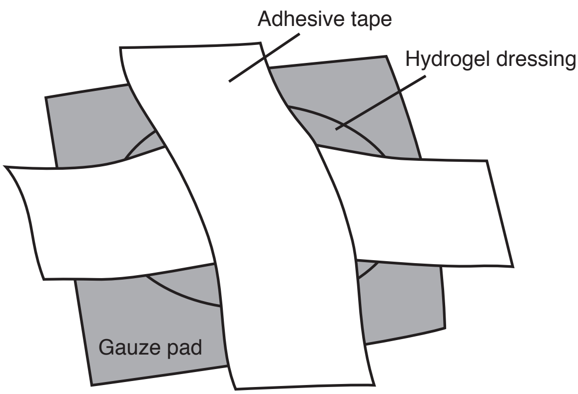

Figure 20. *Other ways of protecting blisters. Hydrogel dressings such as Spenco 2nd Skin (Spenco Medical Corporation, Waco, Tex) or a polyurethane film such as Tegaderm (3M Company, St Paul, Minn) can be afixed to the blister and covered with a pad and tape. Illustration: Courtesy of the US Army Research Institute of Environmental Medicine (Natick, Mass).*

Metatarsalgia

Metatarsalgia is a descriptive term for nonspecific, painful overuse injury of the foot. The usual symptom is localized tenderness on the sole of the foot under the second or third metatarsal head (Figure 21). Sutton[176] reported a 20% incidence of metatarsalgia during a strenuous 7-month Airborne Ranger physical training program that included regular load carriage. One study[131] reported a 3.3% incidence of metatarsalgia after a single, strenuous 20-km walk with soldiers carrying 45 kg.

Metatarsalgia is usually associated with foot strain caused by rapid changes in the intensity of weight-bearing activity.[177] Walking with heavy loads can be a predisposing factor for metatarsalgia, because this might cause the foot to rotate anteroposteriorly around the distal ends of the metatarsal bones for more prolonged periods of time, thus resulting in more mechanical stress in this area.[49]

Treatment is conservative and includes rest, use of ice packs, elevation of the foot, and antiinflammatory medications. A metatarsal pad can be used. If symptoms persist, despite these conservative measures, further evaluation for more serious problems (eg, fractures, tumors) is warranted.[178]

Stress Fractures

Lower extremity stress fractures are common in military recruits[179–184] and have also been reported in trained soldiers.[184] During the Central Burma campaign in World War II, 60 stress fracture cases were reported in one infantry unit during a 483-km road march.[185]

Stress fractures are attributable to repetitive overloading of bones during activities, such as road marching. The most common areas of involvement are the lower extremities, especially the tibia, tarsals, and metatarsals.[179,185–190] For metatarsal stress fractures, tenderness is generally localized on the dorsal side of the metatarsal shafts, which distinguishes the pain from metatarsalgia (Figure 22). Figure 23 shows x-ray films of a metatarsal stress fracture when the patient first presented and 3 weeks later. Generally, a period of time is necessary before stress fractures are apparent on x-ray films.

Demonstrated risk factors for stress fractures include the following:

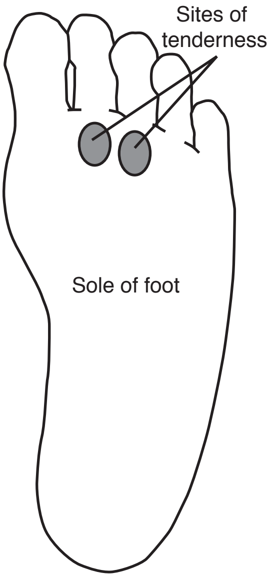

Figure 21. *Sites of metatarsalgia. The usual symptom is localized tenderness on the sole of the foot under the second or third metatarsal head.*
Illustration: Courtesy of the US Army Research Institute of Environmental Medicine (Natick, Mass).

- female gender,[179,184,191–194]
- white ethnicity,[179,195–197]
- older age,[179,196,197]
- taller body stature,[182]
- high foot arches,[198,199]
- low aerobic fitness,[192,196]
- prior physical inactivity,[182,196,197]
- older running shoes,[197]
- genu varus,[200] and
- cigarette smoking.[195,201]

Other factors that might increase risk include load carriage distance[184,202] and walking style.[182,203]

A number of interventions have been tested in an effort to reduce the incidence of stress fractures.[191,197,204–210] All studies were conducted in basic combat training. Successful interventions include reduced running mileage,[204] neoprene boot insoles,[206] and calcium/vitamin D supplementation.[211,212] A multiple intervention study in Australian basic training demonstrated that reducing march speed, allowing trainees to march at their own step length (rather than marching in step), running and marching in more widely spaced formations, running on grass, and

Figure 22. *Symptom of metatarsal stress fracture. Tenderness is generally localized on the dorsal side of the metatarsal shafts, which distinguishes the pain from metatarsalgia.*

reducing running mileage were successful in reducing female pelvic stress fractures.[205]

Stress fracture treatment includes a long period of rest, use of ice packs, and antiinflammatory medications. If the patient has to be mobile, crutches are necessary.

Knee Pain

Knee pain is another condition that has been associated with load carriage. Dalen and colleagues[213] reported a 15% incidence of knee pain (17 cases of 114 subjects) during their load carriage study. Knapik and colleagues[131] reported only a 0.6% incidence of knee pain (2 cases of 335 subjects) following a single strenuous walk, but the two cases resulted in a total of 14 days of disability.

Knee pain is difficult to diagnose. Various disorders include patellofemoral pain syndrome, patellar tendonitis, bursitis, and ligamentous

Figure 23. *X-ray films of a metatarsal stress fracture when the patient first presented to the clinician (left) and 3 weeks later (right).*
Photographs: Courtesy of Keith G. Hauret, MSPH, MPT.

strain. These conditions can arise from an abrupt increase in road marching mileage or intensity or from climbing hills if service members have not been conditioned for this activity. Treatment includes rest, use of ice packs, and antiinflammatory medications. Quadriceps and hamstring strengthening and stretching exercises, along with heel cord stretching, may be important to prevent recurrence.[214]

Low Back Injuries

Low back injuries can pose a significant problem during load carriage. In one study,[131] 50% of the soldiers who were unable to complete a strenuous 20-km walk reported problems associated with their backs. Dalen and colleagues[213] reported frequent problems with back strain during a 20- to 26-km walk. Low back injuries are difficult to define because the pain might result from trauma to a variety of structures, including spinal discs, the ligaments connecting the vertebral bodies, nerve roots, or supporting musculature.[177]

Heavy loads can be a risk factor for back injuries.[137] This could be because heavier loads lead to changes in trunk angle, which can stress back muscles,[52,53,215] or because heavier loads do not move in synchrony with the trunk,[53,216] thus causing cyclic stress of the back muscles, ligaments, and spine.[52,53] Framed packs exert a consistent anterior force on the lower back, and it has been suggested that this force could contribute to low back pain and soreness.[58] Walking with a frameless pack for a relatively short period of time (18 min) results in a greater anterior curvature of the spine, which could result in moments of greater posterior-compressive/anterior-tensile forces on intervertebral discs.[217] The double pack can help reduce the incidence of back problems because it results in a more normal posture and eliminates prolonged bending of the back.[49,58] Thus, better load distribution could reduce back injuries. Also, a general overall strengthening and warm-up program involving the back, abdomen, hamstrings, and hip muscles can assist in prevention.[177]

Rucksack Palsy

Rucksack palsy is a disabling injury that has been widely reported in association with load carriage.[75,176,218–225] The incidence of rucksack palsy was reported to be, respectively, 1.2/1,000 and 0.2/1,000 in US Army basic training when wearing a rucksack alone versus a rucksack with a frame and hip belt[218]; the incidence in Finnish basic training was reported to be 0.5/1,000 recruits.[226] It is hypothesized that the shoulder straps of a backpack or the top portion of individual body armor when in certain postures can cause a traction injury of the C5 and C6 nerve roots of the upper brachial plexus. In minor cases, compression results in entrapment of the long thoracic nerve. Symptoms include numbness, paralysis, and cramping, and minor pain in the shoulder girdle, elbow flexors, and wrist extensors. Long thoracic nerve injuries usually present with "scapular winging" (Figure 24) because of weakness of the serratus anterior muscle. Sensorimotor deficits from rucksack palsy injuries are usually temporary, but, in some cases, can result in a chronic condition. Nerve conduction studies and electromyographic studies might be necessary to document this condition.[218,221]

Use of a backpack frame and hip belt has been demonstrated to reduce the incidence of rucksack palsy,[218] presumably by reducing pressure

Figure 24. *Scapular winging.*
Photograph: Courtesy of Wikipedia.org. From http://en.wikipedia.org/wiki/ File:Wingingofscapula.jpg.

on the shoulders.[57,58] Hypothetical risk factors for rucksack palsy include heavy loads, improper load distribution, and longer carriage distances.[137,218] Height, weight, body mass index, or aerobic fitness were not risk factors in Finnish basic training.[226]

Meralgia Paresthetica

Meralgia paresthetica is an abnormal condition characterized by pain and paresthesia in the outer anterolateral thigh. It is caused by a compression of the lateral femoral cutaneous nerve, a sensory nerve branch of the L2/L3 spinal area. A recent report of two cases of this disorder suggests that when soldiers are wearing body armor and are seated for long periods, the lower edge of the body armor may compress the inguinal region, thus resulting in a compression of the lateral femoral cutaneous nerve and leading to pain and paresthesia. Symptoms generally resolve with removal of the chronic compression.[227]

Influence of Load Carriage on the Performance of Other Tasks

A significant consideration from a military perspective is how well service members are able to perform military tasks during load carriage. Load mass, load volume, and load distribution seem to be important variables. As the mass increases, there are systematic decrements in the performance of specific tasks (eg, short sprints, agility runs, ladder climbs, and obstacle courses).[67,228] The decrement in performance of such tasks is estimated at about 1% per kilogram load.[67] Loads of greater volume will inhibit movement under obstacles. The distribution of the load within the backpack can also influence performance of specific tasks.[67] Wearing of individual body armor (10 kg) results in increased perceived exertion and decrements in pull-up performance, flexed arm hang time, and maximal stair-stepping ability,[91] which may be relevant to some soldier tasks like climbing over obstacles and movements in urban buildings.

In some operations, service members are required to walk long distances and perform critical military tasks at the completion of the march. Very strenuous marches (maximal speed with loads of 34–61 kg over 10- to 20-km distances) lead to postmarch decrements in marksmanship and grenade-throwing distance.[64,109,144] Decrements in marksmanship are presumably attributable to small movements of the rifle, resulting from fatigue of the upper body muscle groups, fatigue-induced tremors, or elevated heart rate or respiration.[64,144,229] The decrements in grenade-throwing distance might be from nerve entrapment syndrome[218,221] or pain in the shoulder area, both resulting from pressure of the rucksack straps. Lower body muscular power (as measured by the vertical jump and Wingate's Anaerobic Test [which measures anaerobic capacity using a bicycle ergometer]) and muscle strength do not appear to be adversely affected by prolonged pack load carriage.[64,109,144,230]

Summary

There are several ways to improve military load carriage. The techniques most available to unit commanders are load reduction, load redistribution, and physical training. Load reduction can be accomplished by tailoring the load to the specific objective and by using special load-handling devices. Commanders must make realistic risk analyses and then take only the equipment necessary for the mission. Special combat load carts are available that could be useful in special situations (eg, marches on unobstructed terrain or in close resupply operations).

Load redistribution can be accomplished by placing equipment more evenly around the torso. Current load carriage systems have attachment points and pockets that can be useful for moving some items from the rucksack to the front of the body. Items carried on the front of the body should be those likely to be needed suddenly or needed often. The most advantageous distribution of the load in the pack might depend on the type of terrain. On roads or well-graded paths, placement of heavy items high in the pack is preferable for maintaining a more upright body posture and reducing low back problems. On uneven terrain, a more even distribution of the load within the pack is more helpful to maintain stability. Load reduction and redistribution can reduce energy cost, decrease injuries, and improve performance on tasks following load carriage.

Physical training that includes aerobic exercise, resistance exercise, and road marching should be performed on a regular basis. Appropriate programs can be tailored to unit needs based on previously successful programs. Road marching should be conducted at least twice each month, with loads that service members will be expected to carry in unit operations (this could be in place of regular physical training). Load and distance should be increased gradually over sessions until a maintenance level has been achieved. New unit members should be given time to adapt through the same gradual program. Regular physical training has been shown to increase march performance and might reduce injuries.

To some extent, the selection and proper use of equipment can assist in reducing load-carrying stress. The MOLLE pack has a frame with a well-padded hip belt that reduces pressure on the shoulders, results in less perceived strain, and reduces the incidence of some injuries. Frames and hip belts can improve service members' performance on tasks requiring use of the upper body. Equipment such as the sternum strap on the MOLLE packs reduces stress by allowing pressure to be distributed to other parts of the body. The MOLLE pack also provides some ventilation across the back because of its external frame construction. New load carriage technologies that are being tested and will become available will use many of the ideas and principles discussed in this monograph.

It is desirable to reduce load carriage-related injuries that impair performance, cause discomfort and disability, and result in a loss of manpower. The use of hip belts can reduce the incidence of rucksack palsy. Keeping the feet dry using an acrylic, polypropylene, or nylon inner socks combined with wool or wool-polypropylene outer socks will reduce the incidence of blisters. Antiperspirants (applied for at least three consecutive days before a march) and frequent changes of socks can also be helpful. Blister incidence can be reduced by using Spenco insoles (Spenco Medical Corporation) and by distributing the load more evenly around the torso (both of which can reduce frictional forces around the foot). Physical training directed at improving aerobic fitness, along with regular load carriage marches, can reduce the incidence of stress fractures and blisters. In basic training, stress fractures can also be controlled by using neoprene insoles, limiting running mileage, allowing trainees to march at their own stride length, and using more widely spaced formations.

Making loads lighter, improving load distribution, using appropriate physical training, selecting proper equipment, and choosing specific techniques directed at injury prevention will all facilitate load carriage. Suitable changes will allow service members to continue missions at lower energy costs and with fewer injuries, and be better able to perform other tasks.

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