

LOAD STRESS; CARRIER STRAIN: IMPLICATIONS FOR MILITARY AND RECREATIONAL BACKPACKING

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ABSTRACT

This paper reviews a growing literature on the stress of backpacking, particularly in military situations. Conceptual issues are raised and the implications for recreational backpackers are addressed. Under moderate to fairly heavy loading the energy cost, per kg total load carried, per hour, relates almost linearly to walking speed. Empirical data from studies in this unit are presented as benchmark indicators for use by recreational backpackers.

INTRODUCTION

The well-being, not to mention the safety, of serious and casual recreational backpackers alike in large measure relates to the optimisation of loads carried: safe loads and efficient load distributions are as important as safe trails and conducive environmental factors in minimising untoward effects of backpacking. While appreciation of the lore of backpacking may give the serious hiker a “competitive edge”, the same knowledge has occupational significance for mail-carriers and for military personnel, to mention a few obvious examples. Moreover, the principles revealed by a review of what is known about backpack stresses *per se* can readily be transferred to any form of load-carrying. The purpose of this review paper, therefore, is to bring together, from diverse sources not usually accessible to the recreation fraternity, the collected wisdom of researchers in fields as diverse as industrial ergonomics, recreation and military medicine. It is suggested that while these domains reflect very different perspectives on the problem of load-carrying, their synthesis enhances our understanding of the issues involved. Thus the manual labour ethos is driven by a need to ensure that stresses can be safely borne over daily 8-hour shifts with no cumulative ill-effects in a working lifetime. In contrast, the military ethos is driven by an imperative to engage successfully in the field, often regardless of the cost. Sandwiched between these two, the recreational ethos aims to set pleasurable challenges of submaximal intensity while recognising that, occasionally, environmental circumstances may call on untapped reserves, sometimes as a matter of survival. The serious backpacker, then, is someone well versed in the issues involved in load-carrying both in terms of cause (external stresses imposed) and effect (internal strains taken). This article therefore surveys the fields of military medicine and industrial ergonomics for information of practical relevance when applied to recreational backpacking.

There has been a long history of military concern relative to load-carrying (Cathcart **et al.**, 1923). The problem is not trivial because the successful accomplishment of military objectives often demands forced marches in which personnel may have to carry over twice the normally recommended load (Dept. of the Army, 1990) including communications gear, weapons, ammunition, food, water and body armour. This explains why the issue of military load-carriage is taken very seriously in the research programme of arguably the most powerful, and most mechanised, military force on earth (Sampson, 1988). This **ad hoc** "doubling" of recommended loads equates in the US Army to instances of 76kg-loaded marches, as against 32kg recommended loads.

Domestication of large pack animals, motorisation of draught vehicles and explosive increases in technology have not eliminated the age-old problem of personal lift-and-carry stresses. It is estimated that in the most mechanised and automated Western societies 30% of all materials handling and carrying is done manually. Carry-aids such as rucksacks have as one purpose the optimisation of efficiency and comfort, both of which are compromised by the fact that human morphology is poorly suited to load-carrying. The design of rucksacks has been seriously tackled both in recreational contexts (Henning, 1978; Meir, 1980) and military contexts (Johnson **et al.**, 1995) in which it makes sense to maximise freedom of movement and ease and comfort of load-bearing. In military contexts efficiency may superficially appear to be the sole criterion in any situation, but there is growing awareness that human efficiency is not solely specified in mechanical terms: perceptual factors dictate motivation, task-satisfaction, and willingness to perform and consequently affect efficiency, whether in civilian or military contexts.

Need For Interdisciplinary Study of the Problem

Traditionally research into load-carrying efficiency has been conducted through the relatively tunnel-visioned approaches of individual disciplines: orthopaedics and march-fractures; physiology and energy-cost; biomechanics and foot-floor force transmission; or psychology and pain-perception. Each approach contributes something to our understanding of load-carrying efficiency but not in a generalisably useful way applicable to field conditions.

The available literature, therefore, reflects intra-disciplinary findings as they are, rather than inter-disciplinary findings as they should be. As an example, in a recent study focusing on stress perception under two military carry-pack configurations (back-pack vs back-plus-front pack), volunteer riflemen exhibited elevated heat illness indices with the latter pack relative to the former (Johnson **et al.**, 1995). Since the study was perceptually focused, the possibility of reduced evaporative sweat loss through the chest, as a factor in impaired thermoregulation, was not measured.

Even in the most recent review paper available (Knapik **et al.**, 1996), the authors are forced to review physiological, biomechanical and medical aspects of military load carrying as separate entities, although the strain taken by the backpacker on a hike is a "Gestalt" of interacting environmental stress factors.

Many of the earlier studies on load carrying capability have controlled the load in absolute mass (kg) terms: Schoenfeld **et al.** (1977; 1978), Nag and Sen (1978), Borghols **et al.** (1978), Soule **et al.** (1978), Pimental and Pandolf (1979), Levine **et al.** (1982) are examples. More recently the common practice has been to express loading in relative units. Saha **et al.** (1979) for instance expressed the load in percentage of VO_2 max, and Gordon

et al. (1983) expressed load in percentage of body mass in order to factor-out effects of gross morphological differences between load carriers.

Most analyses of work done in carrying simply quantify the undulations of the common centre of mass of walker and load (external work). But this fails to take account of "internal" work done (potential and kinetic energy changes within and between body segments; work done by, or on, muscles). External work done may be as low as 16.2%, but Pierrynowski **et al.** (1981a;b) have shown that energy flow within the segments accounts for two-thirds of the observed total energy exchange, the remaining third occurring between segments. These authors conclude that biomechanical assessments provide more information about load carrying than is available from metabolic data alone. Gordon and co-workers, investigating load carriage on the treadmill, found that 'external' factors increase in proportion as loads are increased, so that their metabolic demands are comparable, and linearly related to work-rate (Gordon **et al.**, 1983).

If we combine biomechanical, physiological and perceptual optima we could probably reach a near-universal consensus for male backpackers of 72kg mass: a load of one-third body-weight carried at a pace eliciting no more than one-third VO_2 max energy cost. But these ideals are operationally impractical: as Renbourn (1954) made clear, the loads carried by a soldier are always a compromise between physiological sense and military necessity: the challenge is to find ways to reconcile these factors. In recreational hiking situations the actual loads borne by individuals of diverse capacity in a group are typically determined in a very **ad hoc** manner; strains taken, therefore are not similar between individuals in the group.

Nature of the Stress of Load-Carriage

The biomechanical problem of efficient load-carrying was understood and no doubt effectively addressed in pre-Roman times. There is no mystery to the problem of safe and efficient lifting and carrying. Yet musculo-skeletal strain will continue to plague all occupations in which loads are moved, even in the twenty-first century. Fire fighters carry respiratory oxygen tanks as back packs which inevitably reduce their mobility and increase their fatigue (Louhevaara **et al.**, 1988; Smolander **et al.**, 1985). Nurses and other health-care professionals who lift patients are plagued by back-related occupational stresses (Stubbs **et al.**, 1980; 1983; Stubbs and Buckle, 1984). Mail-carriers are occupationally stressed and the subject of on-going applied research aimed at ameliorating their plight (Ilmarinen **et al.**, 1984; Gerber **et al.**, 1992; Bloswick **et al.**, 1994; Dempsey **et al.**, 1996; Lin **et al.**, 1996). Military stretcher-bearers are the subject of research in large (Tharion **et al.**, 1993) and even small (Sovtic and Bevc., 1987) armies. So clearly no definitive and enduring solution is possible. This is because changes in technology mean continual changes in the nature of the objects being borne, and because changes of a demographic nature mean that there are nutritional, morphological and attitudinal changes over time which impact on human ability. Body-armour routinely worn on forced marches in Crusader campaigns is today too small to fit even the female descendants of those involved.

So the two principles of safe load-carrying: nominal load and closeness of its distribution to the load-bearer's centre of mass, have continually to be re-addressed to fit ever-changing circumstances. The mechanical solution is superficially simple; keep the load as close as possible to the centre of mass of the carrier (Malhotra and Gupta,

1965; Soule and Goldman, 1969; Winsmann and Goldman 1976). This often translates into designs which share the load between chest and back packs, which most have found to result in a reduced energy cost of carrying (Daniels, 1953; Vanderbie, 1953; Datta and Ramanathan, 1970; Ramanathan **et al.**, 1972). In the few instances where front-back packs were not shown to be more efficient than whole back packs (e.g. Legg and Mahanty, 1985), this is probably due to differences in pack design between studies. The recreational hiking fraternity has, in general, not taken well to front-and-back pack designs: the rucksack is an entrenched design.

There are four essentials in the design of any load carrying equipment if minimisation of energy cost is the criterion:

- (1) local musculo-skeletal strain must be eliminated (largely by balancing loads evenly and keeping them close).
- (2) posture must be kept as close to the unloaded state as possible.
- (3) gait kinematics must be kept natural.
- (4) pressure must be minimised in the chest region.

The above guidelines are as valid today as when first presented (Lippold and Naylor, 1950).

Knapik **et al.** (1996) have recently cautioned that energy saving via front-back packs may well be offset by the mechanical restriction of the chest pack in military situations such as when firing weapons, or putting on protective masks. As the nature of combat engagement changes over time, so too does the nature of the physical stresses experienced by individuals. Thus Vanderbies' experimental study of military load distributions in 1953, though sound, was valid only for conditions pertaining around the time of the Korean conflict, and over 40 years later can do no more than make suggestions as we address twenty-first century load-carrying problems (Vanderbie, 1953).

Knapik and associates have very recently warned that acute medical problems brought on by load carrying, ... "can adversely affect an individual's mobility, and in a military situation, reduce the effectiveness of an entire unit" (Knapik **et al.**, 1996). These medical problems are in the main musculo-skeletal injuries of biomechanical origin (see below).

Haisman (1988) presented data on dress, assault dress, combat order, marching order and additional equipment weights to be carried by a British infantryman. Under marching orders the breakdown is: 7kg of clothing; 19.4kg of ammunition, weapon, and digging tool; 3.7kg of provisions and warm clothing; 10kg of extra clothing, rations, rucksack and sleeping bag, plus **ad hoc** accessory equipment up to 16kg. Thus at least 40.2kg and up to as much as 56kg may have to be carried by an infantryman into battle. In fact McCaig and Gooderson (1986) showed that up to 68kg was carried into engagements in the Falklands conflict. What this means is that 60% to 100% of the carrier's own body mass is typical of operational conditions.

While on the issue of clothing as possible mechanical incumbrance and as load **per se**, it is important to stress the observation of Cathcart **et al.** (1923) recounting World War I conditions in the trenches of Europe: dry equipment loads of 27kg, when soaked with water and clogged with mud increase to 43kg burdens. Haisman (1988) argues that modern water-resistant clothing minimises wet-load, but that heavy modern weaponry offsets

the gain with no real net improvement since World War I. Hikers in our mountainous regions have learned, usually the hard way, how non water-proofed wet gear, particularly sleeping gear, can add weight unnecessarily.

In a standing position weight carrying does not influence O_2 uptake, HR or V_E (Borghols **et al.**, 1978; Pimental and Pandolf, 1979). However, when the loaded subject begins to walk, energy expenditure rises as a function of load, terrain factor, temperature/humidity, speed and gradient. Until external stress factors become excessive the relationship between load carried and heart rate, O_2 uptake, pulmonary ventilation and blood pressure is linear. For loads up to 30kg Borghols **et al.** (1978) found that each 1kg increment added $33.5\text{ml}\cdot\text{min}^{-1}$ to the O_2 uptake; $1.1\text{beats}\cdot\text{min}^{-1}$ to the heart rate and $0.6\text{l}\cdot\text{min}^{-1}$ to V_E . This physiological analogue of Hooke's Law breaks down at O_2 uptakes above 50% VO_2 max. However, the fact that gross physiological measures of working strain give no indication when standing while loaded by external weight, does not mean that strain is not being taken: Pimental and Pandolf (1979) showed that perceived exertion ratings are very sensitive to static load.

Several reports of a medical nature have described the effects of single load-carrying excursions, with incidence statistics ranging from 24% to 90% of those involved (Dalen **et al.**, 1978; Myles **et al.**, 1979; Cooper, 1981; Knapik **et al.**, 1992). The majority of these involved the back and/or lower extremities.

Effect of Load on Gait Pattern

The fundamental mechanical response to load-carrying is to increase the percentage of stride-time when both feet are on the ground. To achieve this the swing phase of the stepping limb is proportionately reduced i.e. single support time is reduced, but not total foot-contact time (Charteris, Nottrodt and Scott, 1989; Charteris, Scott and Nottrodt, 1989; Ghori and Luckwill, 1985; Kinoshita, 1985; Martin and Nelson, 1986; Harman **et al.**, 1992). The obvious effect of this increase in percentage of stride devoted to double support time is to extend and strengthen the base of support while loaded. In heavily head-loaded conditions (Charteris, Scott and Wall, 1986) and indeed under all forms of loading this may lead to a decreased stride-length with increased cadence for the given speed relative to unloaded walking: what Charteris and co-workers have termed a "mincing" gait.

The next most evident effect of loading, if a backpack is used, is the increase in trunk lean in order to keep the load better balanced over the base of support (Kinoshita, 1985 and Harman **et al.**, 1992). Depending upon the distribution of the external load this may, but does not necessarily, increase the stress on the muscles of the back. Kinoshita (1985) found, for example, that back stress may be reduced if front-back packs reduce forward lean.

The knees flex more under loaded walking, to cushion the impact of weight-bearing. Dalen **et al.** (1978) have reported a 15% incidence of knee pain in Swedish soldiers following a strenuous march. Sharkey **et al.** (1995) tested the hypothesis that tension in the toe flexors helps to counteract the moments placed on the metatarsals by body weight. Their point of departure was to note as high an incidence of metatarsal stress fractures in military recruits after long marches as occurs in athletes after episodes of overtraining involving running or jumping. These authors argued that physiological fatigue due to strenuous repetitive foot-loading reduces the tension of forefoot flexors (flexor hallucis longus; flexor digitorum longus), thereby increasing metatarsal strain per cycle, and that this in turn predisposed the loaded forefoot to stress fractures. Their tests on fresh cadaveric specimens bore out this

hypothesis. The implications, for reduction of weight-loaded marching on non-resilient surfaces, or rough, fatigue inducing terrain, are dramatic: loads should be as light as possible, distributed carefully so as to minimise muscle fatigue in foot planterflexors, and footwear should offer intrinsic plantar support as well as external protection.

Harman and co-workers (1992) found a front-back pack appears to provide some advantage over a backpack for carriage of heavy loads, and Frykman **et al.** (1994) reported that front-back load sharing results in a more normal upright posture under heavy load than a backpack, but does not appear to ameliorate the effects of fatigue on posture.

The style of walking can be a major contributing factor to inefficiency of load-carriage and consequent fatigue and fatigue-induced stress fractures. Conversely it is known (Charteris **et al.**, 1989a,b) that African women, for instance, can carry headloads substantially more cheaply than army recruits can carry back packs (Pandolf, **et al.**, 1977). Heglund **et al.** (1995) used force-plate analyses to reveal the source of this economy of effort among headloaders. They found that the weight-specific mechanical work required to maintain the motion of the common centre of mass of the body and the load decreases with load in African headloaders, whereas it increases in subjects carrying backpacks. This decrease in work is as a result of a greater conservation of mechanical energy resulting from an improved pendulum-like transfer of energy during each step, back and forth between gravitational potential energy and kinetic energy of the centre of mass.

A Chinese military study of load-carriage (Lang, 1992) compared three different items, matched for weight at 245N but of diverse shape and volume. Volunteer soldiers walked for 1.5h at 5km.h⁻¹. The walkers' own centre of mass was measured before and after each walk and shown to be displaced by load-carrying in relation to the carrying position used. Cadence, (as of course stride length) was altered by the imposed loading condition, even though all loads were constant, at 25kg.

Apart from the mass borne and its distribution, other factors associated with load-carrying require study. Too little heed is paid, for example, to the postures voluntarily adopted by the carrier or to the postures forced upon a carrier by the shape of object(s) to be borne. An example is provided in the case (Sonna and Scott, 1995) of a 19-year-old infantryman in the United States Army who developed a posterior interosseous nerve palsy and transient sensory deficit in a radial distribution after prolonged carrying of an M60 machine gun. This is a condition usually associated with forceful repetitive pronation and supination. The case serves to emphasise the need for ergonomic interventions whose purpose is to design-out faulty carrying and loading postures. This cannot be done without studying load-carriers **in situ** in order to understand (a) what postures are 'popularly' adopted and (b) why. Such surveys hold promise for prophylactic intervention via habit revisions.

When a load-carrying walker speeds-up there will be corresponding increases in foot-ground impulses, shock-absorbing impulse, propulsive thrust force. All phases of the walking cycle will undergo absolute temporal reductions and many will experience reductions in relative terms as well (Han **et al.**, 1992). Thus as the back-packer speeds-up, stride time will shorten, as will all phases of the stride cycle. Moreover total contact time will occur relatively earlier in percent of stride time. Not surprisingly Knapik **et al.** (1992) found knee strain after a taxing walk to be so severe in some cases that the disability lasted two weeks. These authors reported that 50%

of those infantrymen who were unable to complete a particularly demanding forced march reported the cause as back-related. Reynolds **et al.** (1990) also found heavy loads to be a risk factor for back injuries. Poorly designed back-packs clearly cause cyclic stress of soft and osseous tissues of the spine if the loads do not move in synchrony with the trunk (Norman 1979; Pierrynowski **et al.**, 1981a,b; Harman **et al.**, 1992).

Load-carrying studies in the military are a major resource upon which those involved in rucksack design or active hiking can draw. Enlisted personnel must conform in ways that civilians would not tolerate, with the result that overexertions are far more prevalent in the annals of military than of recreational load-carrying literature. A South African example within the present decade, was the practice of having recruits run 20km while carrying 50kg sandbags behind the neck and across the shoulders (Goga and Bhigjee, 1990). In this case the loads were held in place with the arms abducted, externally rotated and the forearms pronated. The result, a medical entity designated as "sandbag palsy".

Typically sandbags are carried "loose", either in the arms or, as was the case in the above paper, across the shoulders. This is a punishment, or at best a work-hardening (conditioning; toughening) application. But conventional "rucksack palsy" is a hazard associated with back-packing in which compression results in entrapment of the long thoracic nerve. What happens is that the shoulder straps "dig-in" and stress C₅; C₆ nerve roots of the upper brachial plexus, resulting in numbness, paresis and pain of the shoulder girdle and/or elbow flexors and wrist extensors. Rucksack palsy has been a concern in military medicine for over half a century (Hauser and Martin, 1943; Daube, 1969; Sutton, 1976; Bessen **et al.**, 1987; Wilson, 1987).

Just as strength requisites are prophylactic against fatigue and strain, so the inevitability of fatigue will eventually cause strength decrements, regardless of physical condition. Clarke and co-workers (1955) studied strength decrements as a result of load carrying. A significant factor in load-carriage is that differential stresses are sustained under identical external loads, on the basis of inter-individual differences in morphology and strength. A recurrent theme of this review is to emphasise the fact that the burden carried is comprised not only of extrinsic factors but also intrinsic loads. The human head, arms and trunk (HAT) in non-obese adults weighs about 74% of body-weight (Williams and Lissner, 1962). Obesity is in large measure an increase in mass in the trunk-abdomen region and its extent, over and above non-obese levels, is to increase the percentage contribution of HAT to total body mass.

Sum **et al.** (1994) studied obese male military recruits in the Singaporean Army. They sampled 12 with BMI between 25 and 30kg.m⁻², 14 with BMI between 30 and 40kg.m⁻² and 16 with BMI over 40kg.m⁻². This compares with an assumed mean BMI of 24.2kg.m⁻² among young adult South African males. While their purpose was not to relate levels of obesity to performance inefficiency it is clear that unnecessary loading, in the form of adipose tissue that must be carried in addition to external equipment, places additional burdens not only on the perfused organs but also on collagenous and osseous tissue, predisposing the overweight load-carrier to fatigue, stress fractures and mechanical inefficiency, at a level in excess of the stresses borne by their non-obese counterparts. It is of interest to note that dietary restriction was not instituted in this study by Sum and co-workers whose sole independent variable was increased activity as it affects fat-free mass and resting energy expenditure. A 5-month programme of combined aerobic conditioning and muscle-strengthening caused weight losses of 8.6kg in the

mildly-obese, 15.7kg in the moderately obese and 22.0kg in the severely obese subjects. Trunk mass decreased, as evidenced by a reduced waist-to-hip girth ratio. Yet fat-free mass was maintained in all groups. Resting energy expenditure reduced by about 6% in the group as a whole.

Obviously the mass being carried is a critical factor in the strain taken by the carrier. Absolute mass is not the key, because bigger individuals are stronger and can safely carry heavier loads. On the other hand relative mass is not a practical solution in military contexts, because there is no easy way to apportion lighter loads to proportionately lighter people so that all carry the same percentage of body weight. The reason is that people of the same mass may differ dramatically in body-composition. Consider two soldiers of 75kg body mass. One has 29%, the other only 9% body fat. If they carry identical 38kg back packs (given that adipose tissue is non-contractile "dead weight" that must be also carried) the lean soldier is in effect carrying only 0.66kg per kg lean body mass, while the obese soldier is carrying as much as 1.13kg per kg lean body mass; i.e. over 70% more. It has long been known that lean body mass is highly correlated with VO_2 max (Buskirk and Taylor, 1957) and this prompts Haisman (1988) to argue that lean body mass is a positive factor in load carrying ability. Relativising loads carried is, however, an option in recreational backpacking: a means for ensuring that one hiker in a group is not unduly taxed (or conversely, underburdened) relative to the rest.

Among well-trained males, greater body mass and skeletal height and width yield faster heavy backpack load carriage times. Anthropometry in fact better predicts load carriage performance than does running ability. Body mass predicts load carriage speed much better than lean body mass. In short, bigger men carry heavy loads faster (presumably more effectively) than do smaller men, and body size is better correlated with load carrying effectiveness than is state of training.

Eke-Okoro and Sandlund (1984) studied the walking patterns of people in the street and divided them into three groups with respect to the loads that they were carrying. One group carried no loads, another carried only handbags or purses and the remainder carried moderately heavy loads in the form of shopping bags or suitcases. They found no significant differences between the first two groups in velocity, but both stride time and length were lower in the group that carried substantial loads. This result indicates a walking pattern in which smaller steps are taken at a higher frequency (i.e. "mincing"). This tendency became a significant characteristic of the pattern of both males and females when substantial loads were carried. Speed reduced significantly as load-weight increased.

Surprisingly, of seven different modes of load carrying studied by Datta and Ramanathan (1971), the method of evenly-distributed weights carried in both hands (as in common in the Western World when toting shopping bags) produced the highest energy cost, while the Afro-Asian method of head-loading (culturally avoided in the West) was a most economical method: millennia of arduous load-bearing has resulted in a near-universal adoption of the least fatiguing feasible method.

It is clear that back-packing is a relatively low-cost method of load-carriage. Under certain conditions members of the armed forces use the lowest cost (front-and-back) method, though in combat situations there must be a compromise between agility and energy cost, which probably accounts for the popularity of back-packing as a

means of load carriage. Headloading is not more energy expensive than front-back rucksack loading, but, as Soule and Goldman (1969) point out, "... the limiting factor in carrying heavy loads on the head does not appear to be in the energy cost but rather the mechanical load tolerated by the musculature."

The natural response to a loaded back-pack is to lean forward. Frykman **et al.** (1994) showed that trunk lean is minimised by front-back loading relative to conventional back packing.

Several researchers have found that reasonably situated external loads, if very light, add nothing to the energy cost of unloaded walking at the same speed (Charteris and co-workers, 1989a,b). Charteris **et al.** (1986) found that African headloaders can carry up to 20% of their own body weight 'free' of additional energy cost (the obvious reason for this tradition in Africa). Soule **et al.** (1978) walked loaded carriers at slow-to-moderate speeds (3.2 and 4.8km.h⁻¹) and demonstrated that the net energy expenditure, after deducting the "no cost load" is relatively constant at each speed. This constancy of measured O₂ uptake per kg net load, for masses between 30kg and 70kg, obviously depends on the horizontal proximity of the centre of mass of the external load to that of the walker. Thus it has long been known that it is more a matter of load positioning than load weight that drives the energy cost of load carriage. When choosing backpacks, serious hikers should take as much cognisance of load distribution as they do of load weight. Many rucksack designs fall short on this score.

Borghols **et al.** (1978) corroborated the earlier finding of Goldman and Lampietro (1962) that energy cost per kg is not different whether the weight being carried is personal body weight or external additional weight, so long as weight distribution is optimised. Epstein **et al.** (1987) developed a prediction equation for estimating the metabolic cost of running with and without backpack loads under a wide range of speeds, external loads and gradients. This is valid for speeds between 2.2 and 3.2m.s⁻¹ (7.92 to 11.52 km.h⁻¹) and loads up to 30kg. The results correlate well ($r = 0.95$) with others in the literature.

It is impossible to account via a simple equation for the diversity of conditions backpackers are likely to face both in terms of self-imposed loads, distances, walk-rest ratios and environmentally imposed loads of gradient, terrain coefficient, altitude, temperature and humidity, to mention only a few. However, for general purposes it may be useful to compute two starting approximations, based on unloaded energy cost, as proposed by Whittle (1991), who in turn was following work of Inman and colleagues a decade before, viz:

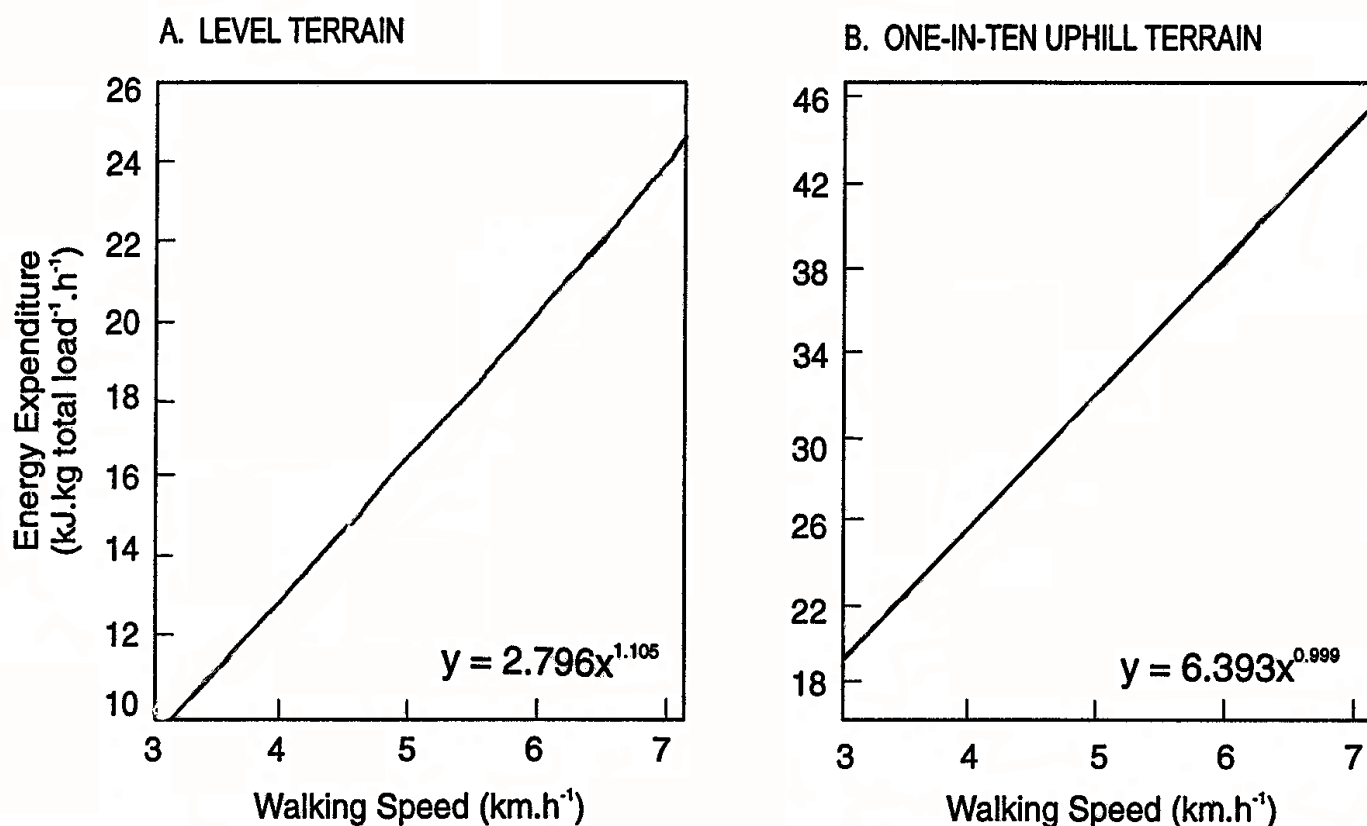


Figure 1: Rough guide to prediction of relative energy cost of (a) level, (b) uphill, backpacking at speeds between 3 and 7 km.h⁻¹. For scientific purposes these relationships would need to be empirically revised for carrier groups of different characteristics from those used in the sample on which these data were obtained (ethnically diverse male backpackers aged between 23 and 55 years; n = 15). The principle, however, is that more definitive guidelines of this type could be established for various age-groups and both sexes, for use by Backpacking Associations.

Energy cost of walking, per unit time: $E_w = (2.23 + 1.26v^2)m$

Energy cost of walking, per unit distance: $E_{\text{kJ.km}^{-1}} = (2.23/v + 1.26v)m$

Where: E_w is the rate of work output, in Watts

m is the walker's mass, in kg

v is the walker's speed, in m.s⁻¹

$E_{\text{kJ.km}^{-1}}$ is the work done, per km walked.

At least with this as basis, the recreational backpacker can use psychophysical perceptual cues to value-judge the cost of load carrying.

Schoenfeld and associates (1977) attempted to establish maximal backpack loads for long distance hiking. Their conclusion (extrapolated to what we assume to be the VO_2 max of average young adult male hikers in S.A. ; 40-49 $\text{ml O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) was that well conditioned males can carry up to 25kg without significantly altering initial VO_2 after a 20km hike. This implies, at least in terms of O_2 uptake, that the carrier's ability to perform work (encamp, erect tent or lean-to, collect firewood, bivouac etc.) at the end of the hike is unaffected: clearly an important consideration.

In the following year Schoenfeld **et al.** (1978) reported on optimal loads for short distance hiking. Their recommendation: 30kg for 12km or 35kg for 6km walks at $6\text{km} \cdot \text{h}^{-1}$ ($\approx 1.7\text{m} \cdot \text{s}^{-1}$). As early as 1923 Cathcart **et al.** had proposed the most efficient load to be 4% of body weight for walks at speeds between 5 and 6 $\text{km} \cdot \text{h}^{-1}$. So there has been a long tradition of research into the problem of enabling loaded walkers to reach their destinations and still be able to function without performance decrement.

Obviously the problem has not been solved, because research continues. Pierrynowski **et al.** (1981a,b) argued that optimal load concepts depend on whether the weight of the walker **per se** is taken into account. So Pierrynowski and associates showed that the optimal external load (if 'load' = bodyweight plus external mass) would be 10kg, whereas if the carrier's own weight is neglected the optimum load would be 40kg or more. These authors made specific comments to the military, after noting that if partial "credit" is given i.e. 50% of body mass-plus backpack, the optimal load is around 17kg, and that the percentage "credit" given to body mass would depend on how important it is that the carrier arrives at his destination in a state of preparedness for work; ... "The military may wish to give 100% and recreational hikers zero". (Pierrynowski **et al.**, 1981a,b).

Recreational hikers commonly carry subsistence and comfort provisions in backpacks (Fletcher, 1974), but their readiness for work at the end of a long trek is not usually a critical issue: quite the reverse may be the case in the military.

Military physiologists are still studying long-walk loaded responses (Patton **et al.**, 1991). It is important to note that the load carried by a soldier is not confined to the backpack and hand-held materiel. As suggested earlier, when one stoops to pick up a pin it is the weight of the head (7.9% body-weight); arms (9.8% body-weight) and trunk (56.5% body-weight), plus the weight of the pin that must be lifted (i.e. a total of almost 75% bodyweight). Similarly, account must be taken, as Phillips and Petrofsky (1984) have shown, of other components of the total load. In this latter study cardiovascular responses (blood pressure and heart rate) of soldiers to isometric neck muscle contractions while wearing standard United States Army SPH-4 helmet and Night Vision goggles were investigated. The subjects exercised the neck in rhythmic isotonic activities and then exerted against an isometric head dynamometer in frontal or sagittal plane making sustained efforts at 70% maximal voluntary contraction (MVC). Characteristic increases in systolic and diastolic blood pressure and in heart rate occurred with these sustained isometric neck muscle exertions. There was an average of 45% increase in blood pressures and heart rate at the end of the fatigue-limited isometric contraction when the helmet was worn. These stress indicators suggest that the issues of efficiency and loads must be viewed holistically, taking into account the nature of all components of loading, including clothing.

Saha **et al.** (1979) determined the acceptable work load (AWL) for Indian workers experimentally, in percentage of maximal aerobic capacity ($VO_2\text{max}$). Their research suggested that 35% $VO_2\text{max}$ constitutes an AWL for sustained physical activity, beyond which level circulatory strain is out of proportion to metabolic work, indicating a state of disturbed "work equilibrium" and consequent physiological fatigue. At 35% $VO_2\text{max}$ the mean energy expenditure was $18.0\text{kJ}\cdot\text{min}^{-1}$ and mean heart rate $109\text{b}\cdot\text{min}^{-1}$. For 50kg Indian workers the following work-related (load-carrying) equations were valid:

$$E = (0.539 \times VO_2\% \text{ max}) - 0.879$$

$$HR = (2.40 \times E) + 66.0$$

where: E = energy expenditure, in $\text{kJ}\cdot\text{min}^{-1}$, and

$$HR = \text{heart rate in beats}\cdot\text{min}^{-1}$$

It is important, however, to heed the authors' warning against generalised use of "acceptable heart rate" levels for individuals of different age, nutrition and health-status. Levine **et al.** (1982) argued that both males and females tend to choose to work at an energy expenditure corresponding to 45% $VO_2\text{max}$ for work durations under 1.5h., and that in self-paced work well-conditioned subjects elect to do 8h-bouts at under 40% $VO_2\text{max}$. When these authors compared trained and untrained men under conditions of self-paced hard physical work, they found that walking speed and absolute predicted energy outputs did not differ between the groups. What did differ, however, were the relative energy expenditures : untrained men at the same task were operating at 44% $VO_2\text{max}$, while the well-conditioned subjects were operating under 35% $VO_2\text{max}$.

Altitude effects must also be factored into the equation for load-carrying efficiency: Greyson and van Graan (1970) calculated that a climb of 915m in 2h would equate to a work rate of 113W, requiring over $2.0\ell\text{O}_2\cdot\text{min}^{-1}$. For subjects whose $VO_2\text{max}$ is around $2.4\ell\cdot\text{min}^{-1}$ this means a climb at near maximum capacity. Seasoned team leaders on such a climb might have heart rates around $100\text{beats}\cdot\text{min}^{-1}$ while unconditioned novices in the group may have heart rates of $160\text{beats}\cdot\text{min}^{-1}$ doing the same work.

Legg **et al.** (1992) found that volunteers showed lower metabolic responses when backpacking an asymmetric two-part 26kg load than when carrying the same load on the shoulders under $4.8\text{km}\cdot\text{h}^{-1}$ speed conditions and over gradients of 0% to 5%. These authors postulated that under field conditions soldiers may choose to carry loads on their shoulders for periods up to 1.5h, but may tolerate backpacks of the same weight for longer periods of time.

The aerobic power of these volunteers was $56\text{m}\ell\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ which is higher than we presume is the mean for young adult South African males. Wyndham **et al.** (1962) for instance, found that miners of diverse South African ethnic groups averaged around $49\text{m}\ell\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. We would expect a mean $VO_2\text{max}$ around $50\text{--}52\text{m}\ell\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in well-conditioned male hikers. What Legg **et al.** found was that under back-packing conditions heart-rates varied from 122 to $135\text{beats}\cdot\text{min}^{-1}$ depending upon gradient, whereas under shoulder-loaded walking the corresponding heart rates ranged from 130 to $164\text{beats}\cdot\text{min}^{-1}$. This latter value amounts to 84% of these recruits' age-predicted maximal heart-rates and indicates the relative severity of the stress. Parallelling these heart-rate increases were metabolic stresses, above mean resting levels, of 5.9 to 8.6 MET (backpacking) versus 6.6 to 9.3 MET (shoulder-

loading). Similar trends, at different stress levels, can be expected to hold in the case of active young adult hikers in South Africa.

Further Considerations

The problems of load-carriage extend far beyond the actual mass moved. They extend to such issues as the footwear which least disadvantages the load carrier. This in turn requires consideration of the mass and mass-distribution of the hiking boot, its shape, the stability it offers to the ankle and the protection it affords the foot. It also requires that cognisance be taken of foot comfort and of the potential for fungal and other infections. Friction blisters are a common injury among recreational backpackers. Boot-induced friction while load-carrying can compromise performance. Reynolds and co-workers (1995) recently investigated these factors in a military context. Volunteers walked on a treadmill at $1.39\text{m}\cdot\text{s}^{-1}$ ($5\text{km}\cdot\text{h}^{-1}$ or $12\text{min}\cdot\text{km}^{-1}$) at a 1% gradient under ambient conditions of 28°C , 25% relative humidity, while carrying 21kg loads. Pre-march treatments with anti-perspirants had no effect on reducing sweat accumulation, blister incidence/severity or hot-spot incidence. The anti-perspirant did, however, reduce irritant dermatitis. In the South African context this issue of hygiene of the habitually enclosed and loaded foot could significantly impact on efficiency, not to mention comfort.

Shephard (1991) has argued that criteria for the acceptability of persons for physically demanding jobs such as police, fire fighting and military personnel are not good: in North America an arbitrary requirement of "above average fitness" is no longer accepted by the courts. Attempts to specify on the basis of age or sex are little better; some women and 65-year-old men have higher levels of aerobic and strength resources than the average 25-year-old male. Shephard argues that the only equitable basis of selecting personnel for physically demanding work seems to be a probationary period of employment. This should reduce the red-tape associated with selection, but it does require a soundly-based and effectively implemented policy. The implication of this is that hiking clubs should see to it that "probationary" performances are regarded as the best overall criterion for selecting who should, and who should not, be allowed to tackle demanding trails. Level of conditioning, in the case of recreational hiking and elite sport alike, is inversely proportional to risk of the sequellae of overexertion.

An Israeli Army study by Stendig-Lindberg and associates (1991) examined military recruits over a 7-month graded training programme, culminating in a 120km forced march. Blood was sampled for estimation of serum magnesium concentration on recruitment, and then up to 15 months after the 120km march. A significant lowering of mean serum magnesium level was found as late as 11 months post-march. Mean serum cholesterol and triglycerides showed a delayed rise well after the 120km walk.

Ekblom and Goldberg (1971) suggested that with work loads involving the use of smaller muscle-groups (as for example carrying loads held manually in place across the shoulders) local factors seem to predominate: i.e. local muscle strain in fatiguing isolated muscle groups as lactate builds up, micro-lesions accumulate and sensations resulting from proprioceptor feedback such as Golgi tendon organ activity dominates the perceived strain. In contrast, when major muscle groups are working, as in locomotor apparatus activation, general cardiovascular and respiratory activity (non-localised strain factors) predominate. At this level the stress is general and cannot be perceptually isolated. The Gestalt nature of the perceived exertion at this level suggests that multiple physiological

responses are integrated in a generalised perception of effort. By establishing a psychological profile of hiking expedition members one is better able to predict how they will react under different conditions and better able to ensure that they are correctly prepared to cope with the pressures placed on them.

While Borg (1978) argued for the universality of application of RPE the use of the Rating scale with semi-literate non-English speaking people has proved to be problematical. As it is essential for users of RPE to fully comprehend the concept and terminology, Scott (1985) proposed a more universally accepted scale using numbers, words and diagrams to assist in identifying the level of perceived exertion.

It has been argued that understanding what people **feel** they are doing may well be more important than understanding what they **are** actually doing (Morgan, 1973; Mihevic, 1981, 1983; Gamberale, 1985; Pandolf, 1978, 1982). The "effort sense" (Morgan, 1973) is evaluated via the rating of perceived exertion (RPE) and has been extensively used as an adjunct to load-stress assessment (Johnson **et al.**, 1995). Wherever it is necessary to carry heavy loads over considerable distances differential ratings for "legs", "arms" and "central" responses could help reveal whether respondents are in poor cardiovascular condition (high central RPE) or whether the stress is localised and associated with poor muscular endurance (high local "arms" or "legs" ratings).

Goslin and Rorke (1986) found, in a study of moderate-speed walking under backpack-loading at 0%, 20% and 40% body mass, that ventilatory, cardiorespiratory, and RPE responses increased linearly with load carried. They suggested that 'local' (musculo-skeletal strain) factors, if accentuated by load carriage, can overwhelm the overall perception of exertion.

We cannot sufficiently stress the need to conduct definitive perceptual studies, sensitive to the psycho-social parameters of our own people, as a changing ecotourism and recreation-seeking demography appears in South Africa. People are not automatons, and backpackers are people. As Borg noted, man responds to the world as he perceives it, not as it is. The definitive recent work in this area is that of Johnson **et al.** (1995), who compared the standard United States Army ALICE ("all purpose lightweight individual carrying equipment") back-pack and a prototype combo chest-and-back-pack under three conditions of load. Volunteer infantrymen completed 20km gravel and tarmac road-marches loaded, on separate occasions, with 34, 48 or 61kg masses. In the case of the ALICE pack the whole load was carried on the back, while in the case of the Double Pack the mass was evenly distributed between chest-pack and back-pack. Using the 68-item Environmental Symptoms Questionnaire developed specifically for stress-analyses in military contexts, pre- and post-march symptoms were obtained. Responses ranged from optimal before, to fatigued and locally sore after each march, with increased severity in proportion to load carried, regardless of type of pack worn. Significantly distress and heat-illness indices were most intense with the Double Pack at 61kg load. As is typical of studies of load-carrying, these results are situation-specific: the authors ensured even mass-distributions fore and aft, but not even volume distributions. In the case of the Double Pack 30% of the volume carried was over the chest, 70% over the back. No mention was made of the effect of this volume distribution on arm motion while walking. One of the significant results of this study, however, was the percentage increase in 20km march time when using the Double Pack, whatever the load. Thus 6% (light load); 14% (medium load); 28% (heavy load) increases in time were associated with the Double Pack configuration.

Nicholson and Legg (1986) found, in a study of stationary repetitive lifting, that soldiers prefer to work at a faster rate with lower loads if given free choice. Extrapolated to load-carrying this would suggest that a fast, mobile, and lightly-loaded platoon may express less stress-related discontent than a slower-moving, but more heavily loaded squad. In their study, when lifting frequency was adjusted, the mean maximal acceptable workload was 94.5kg m.min⁻¹ for a group averaging 1761mm stature; 77.2kg mass (i.e. 413.57 RPI, which is probably a less linear physique than that expected in healthy adult South African males, whose predicted mean RPI is closer to 430.0).

Fatigue Effects, and the Influence of Load-Carrying on Performance of Other Tasks

Perceptual-motor skill is known to be adversely affected by metabolic and/or musculo-skeletal fatigue, and the Tharion study ably demonstrates this generalisation. In a recent study Benn and co-workers (1996) stressed older healthy males (mean age 64.4 years) in various ways, including treadmill walking at 4km.h⁻¹ carrying 9kg and 13.6kg loads. The authors concluded that older adults who engage in weight lifting with heavy submaximal loads are exposed to no more peak circulatory stress than that created during a few minutes of inclined walking. Moreover, the carrying of a 13.6kg load during horizontal walking at 4km.h⁻¹ is no more stressful than climbing only 3 to 4 flights of stairs at a moderate pace. Clearly these data suggest that even older hikers may well be capable of handling reasonable equipment loads without necessarily being exposed to greater risk than younger men, if the form of exposure is properly controlled. These authors employed intra-brachial artery catheters and measured physiological, not perceptual responses. Yet perceptions may be the primary determinants of experienced fatigue and unwellness, regardless of age.

Of great military ergonomic interest is to establish how well soldiers can perform their prime functions during and after load carrying. Several studies have shown systematic performance decrements as load increases. This knowledge is of direct relevance for the serious recreational backpacker. Holewijn and Lotens (1992) showed a 1% performance decrement per kg load carried. Establishing the exact nature of this relationship specific to typical hikers and typical trails would be a major contribution. A strenuous march of 20km under full load at maximal speed could cause post-walk decrements in grenade throw distance and in marksmanship, caused by upper extremity muscle fatigue (Knapik **et al.**, 1991; 1993; Wilson **et al.**, 1987). Clearly, awareness of upper extremity fatigue as a result of backpacking can influence the strategies of the 6-day trailblazer, who must make, rather than simply walk in and occupy, a camp.

Just how a person responds to a specific situation, presuming he has been physically prepared will be strongly influenced by his psychological state; the cognitive and emotional condition of the mind at the present moment.

Understanding the psychology of emotion requires not only the inclusion of Personality tests and the establishment of trait patterns but one also needs to have some measure of the affective state or present "mood" of the individual. In 1971, McNair **et al.** (1971) developed a quick and economical method of assessing the basic, transient affective state of a person: The Profile of Mood State (POMS) identifies mood states, tension, depression, anger, vigour, fatigue and confusion and is a very useful assessment tool to evaluate the present mood-state of an individual. Use of POMS assists in identifying problem areas so that appropriate steps can be taken to overcome such problems before they are too big to handle.

While few will doubt that stress, as imposed by external demands, does affect performance proficiency, the literature is equivocal as to how it is affected. For, while there may well be a high degree of commonality in the effects of stress on bodily or behavioural functions, it is important to realise that these same stressors also produce responses that are idiosyncratic (Hockey, 1979). Modern humans are under constant pressure to cope with ever increasing demands being placed on them. While many individuals appear to be able to cope with stressful demands, and in fact use them to achieve great heights in all walks of life, others withdraw or collapse physically and/or mentally, under pressures perceived to be beyond their control. As external demands increase so individuals must increase their efforts to meet these demands within adaptability limits.

Understanding of the effects of stressful demands is of importance to the backpacker, where the difference between being successful or a loser is small and where the fine tuning of all bodily and mental systems is of crucial importance. It is therefore essential to have some means of assessing an individual's response to a stressfully demanding situation, in order to try to maximize the benefits of the physiological 'boost' resulting from the associated increase in arousal levels (Scott, 1994; 1995).

It is generally acknowledged that in a stressful situation people will experience strain when there is an imbalance between perceived demands and perceived ability to cope with those demands, particularly where failure to meet demands is perceived as having important consequences (Martens 1977; Smith **et al.**, 1988). Thus when assessing the impact of the situation cognizance must be taken of the individual's perception of that situation. In 1994 Scott proposed the Perceived Strain Scale (PSS) as a basic, simple to use, rating chart which will provide a means for making on-site evaluations of the stress imposed by the external demands and the strain experienced by the individual facing those demands. Thus one will have some tangible measure of the athlete's cognitive and affective appraisal of the forthcoming event and be able to adjust coping strategies accordingly. This scale now has international acceptance (Scott, 1994; 1995).

Used in conjunction, RPE, POMS and PSS are three important evaluative tools which could be most helpful in addressing the human element ; by understanding the **human** factor one is better able to bring the best out of each individual and so establish a stronger and more effective unit.

CONCLUSION

It makes no sense to base the loads which hikers carry, and the conditions under which they carry them, on a blind adherence to tradition. Any modern approach to the problem of load-carriage must take cognisance of the interacting needs to optimise total load, redesign equipment and improve load distribution with the anthropometric and perceptual characteristics of the intended users in mind, and in the process to minimise the risks of injury (Knapik *et al.*, 1996).

Load **per se** is not the sole criterion; hiking efficiency is optimised by judicious design of load weight, load location/distribution, freedom of motion, musculo-skeletal (biomechanical), service-organ (physiological) and perceptual-motor (psychological) considerations. Establishing such guidelines requires modern interdisciplinary ergonomic research specific to South African conditions. Figure 1 has been derived by the author, for field-use predictions of heart-rate and oxygen consumption from total load moved (body weight plus external load). It represents no more than a basis for future empirical work specific to Southern African conditions.

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