PSYCHOPHYSICAL ASSESSMENT OF LOAD-CARRYING IN INTERNAL AND EXTERNAL-FRAME BACKPACKS

by

Pierre Meunier

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APPROVED:

K.H.E. Kroemer, Chairman

Walter W. Wierwille
W.W. Wierwille

Jeffrey C. Woldstad
J.C. Woldstad

Blacksburg, Virginia

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(ABSTRACT)

The psychophysical method of adjustment was used to determine whether slight changes in load position and comfort could have significant effects on the maximum backpack load acceptable to subjects. Four males and four females, who were accustomed to walking with backpacks, were given 15 minutes to adjust the load until it was, in their judgment, neither too heavy nor too light for an 8 hour trek. The variables in this 2^3 within-subject experimental design were horizontal and vertical load position, as well as backpack type. The levels of the horizontal load position differed by a distance of 4.0 cm, which corresponds to the difference between the internal and external-frame backpacks used in the experiment. The vertical distance levels were 1/3 and 2/3 of the height of the pack. The pack types (internal and external-frame) were selected on the basis of their harnesses, to provide two distinct levels of comfort.

The results indicated that the horizontal and vertical load positions did not have an appreciable effect on the psychophysically-determined maximum acceptable load, although there was a significant interaction between horizontal position and pack type. There was a significant difference in trunk angle due to Pack type and Horizontal load position. Stride rate was not affected by the treatment conditions, but it decreased significantly with the addition of load. There was a significant difference in comfort ratings between backpacks, with subjects choosing to carry 6% larger loads in the one they rated as more comfortable (the external-frame backpack).

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1. INTRODUCTION

1.1 Backpacks

The backpack is one of the most popular load carrying methods available to humans. The efficiency and practical nature of backpacks have made them the carrying method of choice for heavy or bulky loads that have to be moved over long distances and various terrains. Backpacks have been adapted to a large number of uses, and therefore come in a variety of shapes and sizes. They have had a unique role in load carrying applications in the military, industry and in outdoor recreation activities. In recent years, recreational backpacking has experienced a boom. Partially as a result of this increase in popularity, the evolution of backpack designs has been rapid over that time period. Today's backpacks are designed using state-of-the-art technology and materials in an effort to provide the user with greater comfort and the ability to carry heavier loads over greater distances.

Backpacks have evolved from a simple pack with a set of shoulder straps supporting the load on the shoulders, to a more complex framed system allowing the distribution of load between the shoulders and the hips. Backpacks that distribute the load fall into two categories: external-framed and internal-framed. The external-frame backpack usually has an independent rigid frame (separate from the pack itself) onto which the pack is hung, while the internal-frame backpack integrates the rigid support in the pack, to form the appearance of a single piece pack.

It has long been known that it is preferable to carry the load as close to the body's center of gravity as possible (Parkes, 1869), and one of the advantages of the internal-frame backpack over the external-frame pack is that it follows this basic principle better.

The center of volume of the internal-frame pack lies closer to the trunk than that of an external-frame pack, due to its different design approach. Another characteristic of the internal-frame backpack is that the load is "worn" on the back, meaning that the load contacts the back over a large area instead of only at the hips and shoulders. For these and other reasons, internal-frame backpacks have enjoyed popularity in outdoor recreation, and seem to have taken over as the new generation of load carrying equipment for hikers.

In spite of the apparent advantage of carrying the load closer to the body, the scientific evidence reported in the literature has not shown any significant physiological advantage of the internal-frame over the external-frame backpacks evaluated (Kirk and Schneider, 1992). However, some researchers have argued that this was basically due to a lack in sensitivity of physiological measures in situations where similar load carriage devices are evaluated (Pierrynowski, Norman and Winter, 1981a; Jorgensen, 1985), and recommend other measures. Thus, the use of other approaches would seem appropriate to complement the current body of knowledge by focusing on other aspects of backpack load carrying. One of the goals of this study was to use the psychophysical method of adjustment as an alternative means of measuring differences between backpacks .

1.2 Hypotheses

1. The backpack type and/or the position of the load relative to the back (both horizontally and vertically) have a significant effect on the psychophysically determined Maximum Acceptable Load to be carried.

2. The backpack type and/or the position of the load have a significant effect on the static and/or dynamic trunk angles.

3. The backpack type and/or the position of the load have a significant effect on cadence (stride rate).

4. The backpack type has a significant effect on the perceived comfort during the load carrying task.

2. LITERATURE REVIEW

Load carrying, and particularly load carrying in a backpack, has been the object of considerable attention over the years. Although most studies have been performed with military applications in mind, the findings apply equally to the recreational backpacker. Renbourn (1954) traces the appearance of the word knapsack (coming from the Low German *Knappen-Sack*, meaning a food bag) in the English language to the year 1600 or so, providing some indication of the appearance of this mode of load carrying in Europe. Rucksack is another often used term, which means a sack carried on the "rücken" or back. Although technology has made great strides since, the problems which were encountered with backpack load carrying systems then, were basically the same as they are now: the physical and physiological limits of the human body. The following is a discussion of some of the factors of interest in the present study.

2.1 Factors affecting load carrying

2.1.1 Biomechanical aspects

The field of biomechanics is primarily concerned with the forces exerted by muscles, and those acting on the bones and joints. It treats the human musculoskeletal system as a mechanical system. In static and dynamic biomechanical evaluations, the magnitude and direction of the forces acting on the body (both internally or externally generated) and their point of application, must be known. Knowledge of the forces acting on the body, and of the musculoskeletal posture, allows the forces within the body to be estimated. Several techniques have been developed to predict muscle tension and compressive forces on the skeletal system (Bean, Chaffin and Schultz, 1988), with the ultimate goal of predicting dangerous work situations, and decreasing the potential for injury. The larger the external load, the higher the muscle forces the human body must exert to counteract it and the higher the stress on the muscles and joints. Large external forces or moments may exceed either the muscle or joint capacity, and possibly lead to injury.

From an analysis of the forces involved in backpack load carrying, it can be seen that the position and size of the load will have a direct influence on the posture required for equilibrium of the combined weight of the body and pack. In his study of backpack loads on gait pattern, Kinoshita (1985) noted significant differences in forward lean between varying conditions of load magnitude and position of the center of gravity. Figure 1 illustrates this effect by comparing postures likely to be encountered with light and heavy loads placed in a backpack. The forward lean of the trunk and body increases as their combined center of gravity shifts. Similar effects were reported by Bloom and Woodhull (1987), Klausen (1965), and Martin and Nelson (1986).

The change in posture during backpacking results from the need to counteract the moment generated by the load. Klausen (1965) found increases in activity in the back and abdominal muscles, and a flattening of the lumbar lordosis as a result of load increase. One of the possible consequences of carrying loads for an extended period of time is that this change in posture may lead to long term effects on the spine. Furthermore, its effect may not only cause strain in the musculo-skeletal system, but also in the cardiovascular and respiratory systems (Brown, 1972). Both physiological effects, which will be discussed in more detail below, may reduce the physical efficiency and load carrying capacity of the individual.

Another consequence of change in posture is that it is one of the single most important factors affecting static and dynamic strength. This comes from the fact that changes in joint angles affect both the size of the moment arm the muscle acts upon and muscle length. A small moment arm means that a larger muscle force must be exerted to keep the output force constant. Since there is a relationship between muscle length and the maximum tension that it can exert, a change in muscle length can have a significant effect on the output force as well. The combination of these two factors can be enough to impair the biomechanical efficiency, causing local fatigue at a higher rate than normal. Kinoshita (1985) noted a change in gait pattern due to "abnormal posture", which was amplified by heavier loads. In another study, Martin and Nelson (1986) found a reduction in stride length and swing time accompanied by an increase in stride rate and double support time as the load increased.

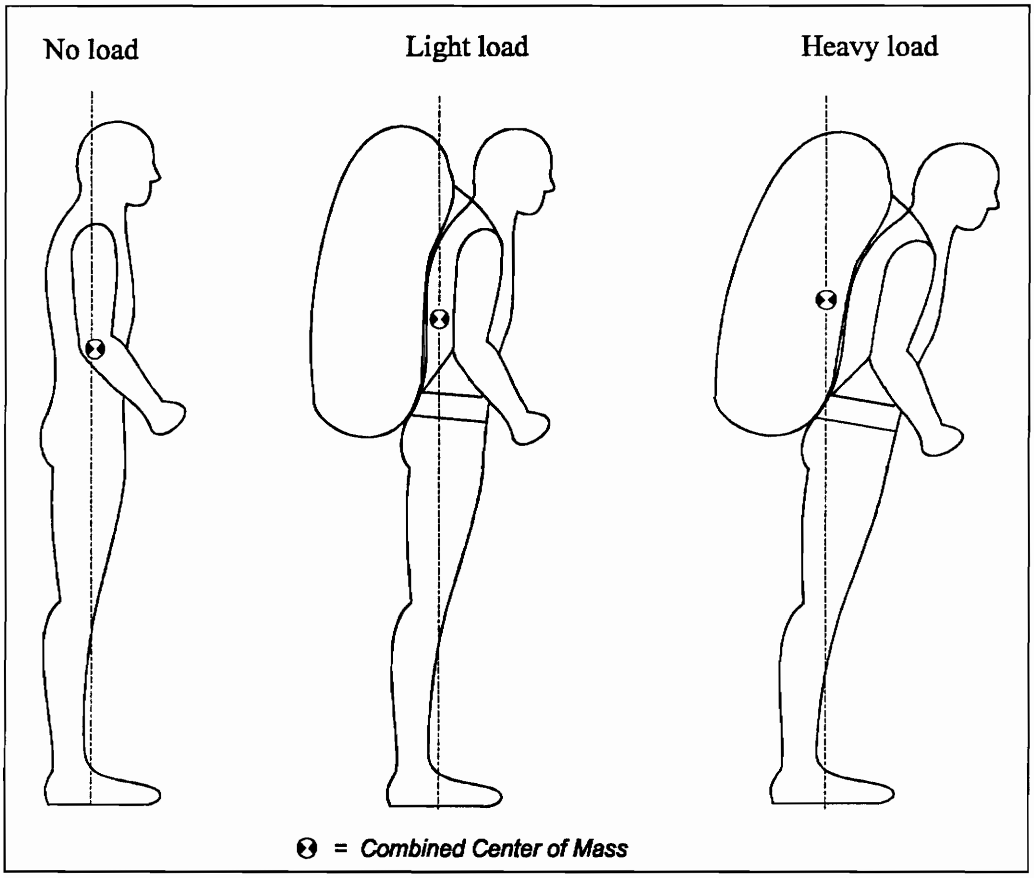

Figure 1. The effect of increasing backpack load on posture.

Bloom and Woodhull (1987) investigated the issue of "postural adjustment" with respect to loads carried in commercially available internal (Lowe Expedition pack) and external (Kelty basic pack) frame backpacks. Significant differences were found between the equilibrium postures of subjects bearing the same load in both backpacks. The authors concluded that the internal-frame backpack affected the posture more, compared to the control, than did the external-frame pack. However, the results were confounded by the considerable difference between the design of both packs, particularly with respect to the position of the center of volume, which was not taken into account. Because the authors chose to use the center of volume of the pack as the center of gravity of the load, the load position appeared to be considerably higher for the external-frame pack relative to the hips, than it was for the internal-frame pack. From a biomechanical standpoint, the position and magnitude of the load can have a significant effect on posture, which could explain their surprising results. A more realistic approach would have been to pack the same items in the same position for both packs, as if the same expedition was planned with both packs. In this case, the real advantage of the internal-frame backpack, namely its closer proximity to the trunk, would not have been confounded with the height of the load on the back.

The height of the load, relative to the waist, was investigated by Bobet and Norman (1984). Loads placed just below mid-back or just above the shoulder level were compared in terms of the electromyographic (EMG) response of the erector spinae and trapezius muscles during walking on a level surface at a velocity of 5.6 $km \cdot h^{-1}$. The significant difference found in the EMG signals, between the two sets of conditions, was attributed to the difference in rotational inertia as the trunk rotated during walking. Although the kinematics of the trunk were not recorded, the authors used a qualitative biomechanical analysis as a basis for their explanation.

In summary, the magnitude of the load, as well as its location relative to the body, are two major considerations in the study of backpack load carrying and load carrying systems in general. In comparing two systems, careful control of these two variables must be exercised.

2.1.2 Physiological aspects

The ability to perform physical work depends, in large measure, on the body's ability to convert food energy into mechanical energy. This ability varies from individual to individual, from day to day and to some extent, even throughout the day. Apart from the metabolic energy transformations, a large number of factors have an influence on work capacity, some of which are physical, and some which are psychological. The complexity of the relationship between these variables, discussed by Åstrand and Rodahl (1977), is depicted in Figure 2.

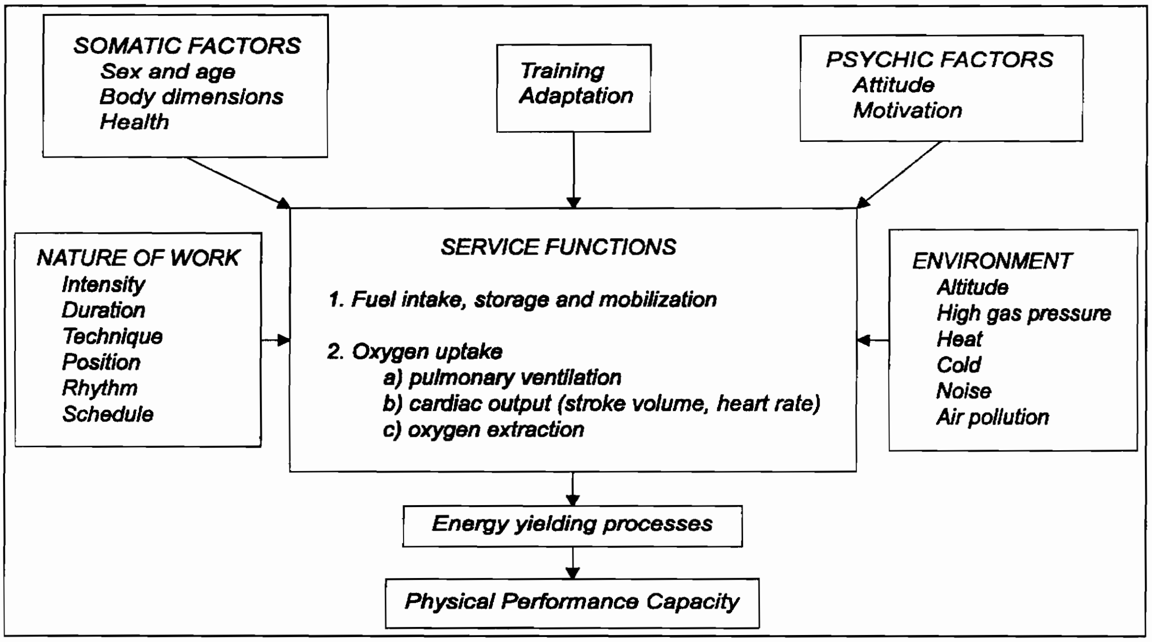

Figure 2. Factors affecting physical performance capacity (adapted from Åstrand and Rodahl (1977)).

Oxygen uptake is a widely used measure of energy consumption in work physiology, because of the known relationship between oxygen and the amount of energy released: 1 liter of O_2 for 5 kcal. An individual's maximal work capacity can therefore be expressed in terms of the maximum amount of oxygen his/her body can consume, or the $VO_{2\ max}$. $VO_{2\ max}$ is the major determinant of a person's capacity to carry loads (Haisman, 1988), and load carrying task limits are therefore usually expressed as a percentage of this value. Acceptable limits for physical work performed over an 8 hour period are based on work paces that do not change the body's homeostasis, e.g. blood lactate concentration (Jorgensen, 1985). These work paces have been determined to be at energy consumption rates not exceeding 50% of $VO_{2\ max}$ for trained individuals and not exceeding 35% of $VO_{2\ max}$ for untrained individuals. The one-third of $VO_{2\ max}$ rule of thumb (Haisman, 1985) appears adequate for most people.

Since $VO_{2\ max}$ is correlated with somatic factors such as gender, age, and body weight (Haisman, 1988), large variations in the population's load carrying ability can be expected strictly on the basis of these factors. In addition, physical performance can also be greatly influenced by psychological factors and the environmental conditions prevailing during the work period. All of these factors are intertwined in a complex manner, and this has made it very difficult for researchers to establish exactly how much load can be carried and under which conditions.

Numerous attempts have been made to provide the definitive upper limit of weight to be transported, using a wide array of experimental designs. In terms of absolute weight, upper limits of 25 to 30 kg have been suggested for individuals in good condition (Cathcart, Richardson and Campbell 1923, Shoenfeld, Shapiro, Portugeeze, Modan and Sohar 1977, Haisman 1988). However, because of the relationship between weight and

VO_2 max, such loads may be adequate for average weight individuals but would certainly represent a very heavy load for a small person. Consequently, many of the recommendations for load limits are expressed in terms of body weight. The traditional rule of thumb is that individuals should be able to carry one-third of their body weight. This would equate to a 23 kg load for a 70 kg individual, which is in agreement with the above absolute weight limits.

Pierrynowski, Norman and Winter (1981b) reviewed the literature in an attempt to determine the optimal load relative to energy expended per kilogram of weight. They found a confusing mass of data which, they explained, was due to differing experimental conditions and data presentation, the linearity or non-linearity of the metabolic rate/load curve, and whether the subjects were given any credit for carrying their own weight. Surprisingly, the optima obtained from the data surveyed ranged from 24% to 56% of body weight, depending on the experimental conditions.

It can perhaps be concluded that there may not be an absolute optimal load, but that there will be local optima depending on walking speed, grade, terrain, environmental conditions, etc.. There have been studies where subjects have been asked to go at their own pace for the performance of a variety of tasks. The self-paced "hard work" energy expenditure of fit male subjects was found to be 494 watts ± 10% (Goldman, 1965; Hughes and Goldman, 1970; Levine, Evans, Winsmann and Pandolf, 1982). Using an equation developed by Pandolf, Givoni and Goldman (1977), and later refined by Pimental and Pandolf (1979), it is then possible to obtain load values or walking rates for various conditions. For instance, by substituting 494 watts into the equation, with 0% grade and on a treadmill, a 70 kg individual would choose to carry roughly 28 kg at a speed of 5.6 km/h, or 40% of his weight in self-paced "hard work".

$$M = 1.5W + 2.0(W + L)\left(\frac{L}{W}\right)^2 + \eta(W + L)(1.5V^2 + 0.35VG)$$

where M = metabolic rate (Watts); W = subject mass (kg); L = external load (kg); V = velocity of walking (m/s); G is % grade; η *= terrain factor (1.0 for treadmill).*

The optimum velocity for backpack load carrying was found to be between 4.8 and 5.1 km/h (Brezina and Kolmer, 1912). Psychophysically established limits of acceptable walking speed while carrying loads are in the vicinity of 4.7 km/h, or 2.8 mph (Snook, 1976). Loads of up to 21 kg could be carried as economically as so much extra live weight, which represented approximately 30% of the subject's body weight (70 kg). Heavier loads were found to bring about both absolute and relative increases in energy output. They also found that it was more economical to increase the load than the speed at which it was carried.

In conclusion, the one-third body weight or one-third $VO_{2\ max}$ rules appear to remain adequate as a first order approximation. Individual factors, such as fitness and lean body mass, can account for large deviations from these rules. A case in point is a study by Nag, Sen and Ray (1978) who reported individuals of 53 kg average body weight carrying up to 100 kg on a treadmill. For convenience, however, body weight was used to determine the starting backpack loads whereas treadmill grade, terrain and velocity were selected such that the metabolic rate would not be excessive during the experiment. An average walking speed of 4.7 km/h (2.8 mph) at 0% treadmill grade was adopted for this study.

2.1.3 Comfort

The aspect of comfort is all too often overlooked as a limiting factor in load carrying. In situations of prolonged load bearing and dynamic exercise, the slightest pressure point can be amplified until it becomes intolerable over time. High local pressure can cause muscular pain and paralysis of the nerves (Noro, 1967). Kirk and Schneider (1992) found increases in rate of perceived exertion (RPE) in the shoulders and legs over time, although the energy expenditure and heart rate were relatively constant, indicating that muscle fatigue was perhaps playing a role in the perception of exertion. While it may be true that there does not seem to be significant difference in energy expenditure measures of internal- versus external-frame backpacks (Kirk and Schneider, 1992; Winsmann and Goldman, 1976), there are other factors, such as muscle fatigue and comfort, that may significantly limit performance. A method of assessing these should therefore be considered as an important element of a backpack evaluation.

Load carrying is really a combination of static and dynamic muscle exertion. In simplified terms, the body must counteract the effect of the load acting on the shoulders, back and hips through isometric and dynamic contractions, while the legs and arms are involved in dynamic exertion. Rohmert (1960) showed the effect of exertion on endurance time. The so-called Rohmert curve shows an exponential decrease in endurance time for contraction forces above 15% of maximum. The implications of this curve are that muscular fatigue will occur for all but modest isometric contractions. Considering the posture imposed by backpack load-carrying and the resultant isometric exertion of some of the muscle groups, it is difficult not to imagine fatigue taking place in some part of the body. A method for the identification of these parts, and the assessment of the magnitude of the sensations of discomfort, was proposed by Corlett and Bishop

(1976). Although aimed at assessing postural discomfort of workers operating industrial machines, the principles can be readily transferred to load carrying tasks.

Corlett and Bishop (1976) reported the results of work performed by Kirk and Sadoyama (1973), where a linear relationship was found between the perceived pain level in the arm during static work (on a five-point scale) and endurance time, in terms of percentage of maximum endurance. By extension, the perception of postural pain was also assumed to be linear. Another concept proposed by Corlett and Bishop (1976) is that the overall level of perceived discomfort is a summation of all the individual sensations acquired either from the human-machine interface or the environment.

In their assessment of postural pain, or discomfort, Corlett and Bishop (1976) settled for the use of a seven-point scale marked "extremely comfortable" at the left end, and "extremely uncomfortable" at the right. The subjects were asked to indicate the point on the scale which represented their current levels of overall comfort. Following this rating, the subjects were asked to indicate on a diagram of the human body (see Figure 3) which body areas were most painful. These areas were noted and covered with small flaps. The next most painful areas were then solicited, and so on, until all of the areas of discomfort were identified. The areas not identified as uncomfortable would be assigned to the "no discomfort" category.

One of the interesting features of the body part rating is that there is no pre-set limit to the number of categories of pain level that will obtained under each test condition. Each separately reported group represents a noticeable difference between them. The sensitivity and usefulness of the scale was clearly demonstrated in the study by Corlett and Bishop (1976), as productivity was shown to increase significantly with decreases in discomfort. This method was adopted for the collection of data on the relative comfort of the two backpacks under study.

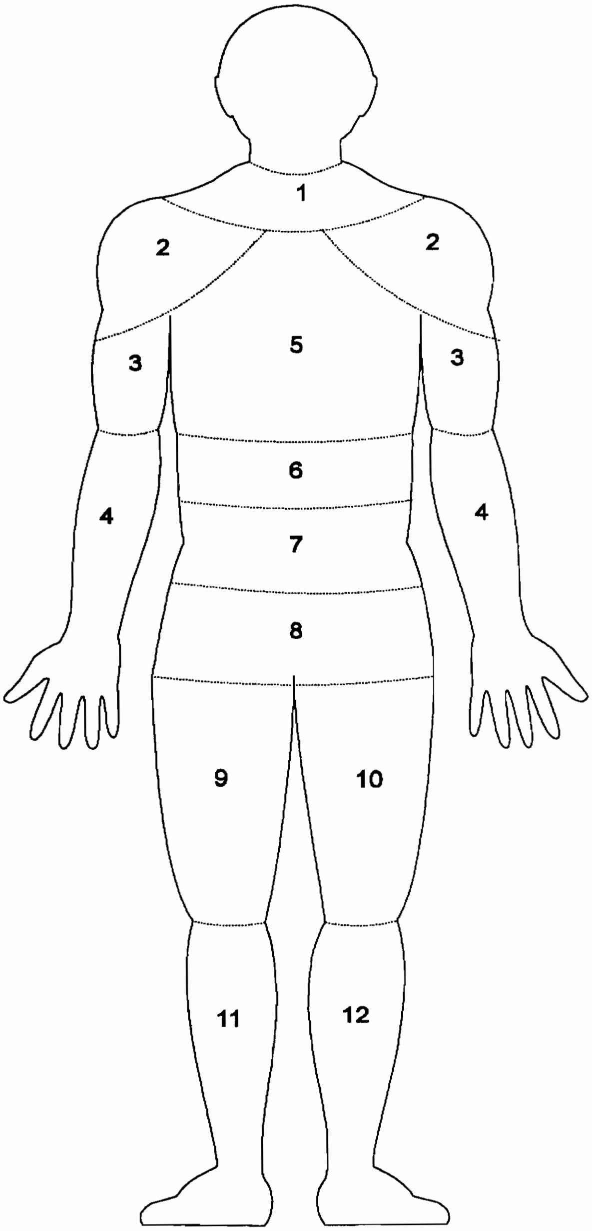

Figure 3. Body regions diagram (adapted from Corlett and Bishop, 1976)

2.2 Methods of evaluation of load carrying

Various types of measures have been used for the assessment of load carrying methods over the years. Although the most commonly used are physiological measures, several other techniques have been employed. The following is a critical review of the literature concerning the two most prevalent methods of evaluation of physical exertion, namely: physiological measures and perceptual measures.

2.2.1 Physiological measures in load carrying

Most of the literature on load carrying has been concerned with the physiological cost of load carriage (Cathcart *et al.,* 1923; Datta and Ramanathan, 1967; Legg and Mahanty, 1985; Renbourne, 1954; Redfearn, Crampton, Williams and Mitchell, 1956), in terms of respiratory, metabolic or cardiorespiratory parameters. These physiological studies have provided valuable information, particularly in the comparison of various modes of load carrying. For instance, Datta and Ramanathan (1967) were able to find significant differences between seven modes of load carriage: Head, Rucksack, Double Pack (front and back packs), Rice Bag, Sherpa, Yoke and Hand modes. Physiological measures have been less successful in discriminating between similar types of load carrying methods, where the load is basically carried in the same position and using the same muscle groups. A study conducted by Winsmann and Goldman (1976) comparing two types of backpacks, concluded that there were no significant energy cost differences between them. They stated that, as long as the weight was "properly distributed over the body", weight *per se* was the most important factor. While that statement may be true from an energy expenditure standpoint, it has been suggested that an evaluation that only considers this variable is incomplete (Kirk and Schneider, 1992).

Legg and Mahanty (1985) came to the conclusion that some physiological responses are simply not detected by cardiorespiratory and metabolic measurements. Their results showed significantly different subjective assessments of different modes of load carrying while the physiological measurements were not statistically different. To understand why this may be the case, it is necessary to understand the type of information provided by each of these measures. The measurement of oxygen consumption is an overall indication of the body's need for oxygen, which is required in the actuation of the muscles during exercise. One of the advantages of this measure, and at the same time its downfall, is that it integrates the amount of oxygen required by all the muscles of the body, large and small. A significant change in the degree of exertion in the larger muscle groups is likely to cause a significant change in oxygen consumption, whereas a significant change in the exertion of smaller muscle groups may not. Relatively speaking, the smaller muscle groups do not contribute much to the overall oxygen consumption, and overexertion may simply go unnoticed. Because of the network of sensors in the human body, overexerted muscles will not go unnoticed, even though their contribution to the overall effort may be small.

The lack of sensitivity to some physiological changes may stem from the fact that energy expenditure is a general workload measure which does not account well for pain or the overexertion of the smaller muscle groups. There are many examples of jobs in sitting or standing positions which have moderate metabolic demands, yet put considerable stress on some parts of the body (Jorgensen, 1985). The same may be true for backpack load carrying, because of the involvement of small and large muscle groups in static and dynamic activity. In fact, it is quite conceivable that local fatigue (in the shoulders and back) may actually become the limiting factor in load carrying , in which case it would be easier to detect subjectively than through the use of physiological measures. In essence, physiological measures appear to be adequate for the detection of large differences, but not for small ones.

Some investigators have suggested supplementing physiological measures with perceptual and biomechanical measures (Kirk and Schneider, 1992). Others have proposed mechanical energy analyses, measures of changes in gait pattern or alteration of muscle activity (Pierrynowski *et al.*, 1981a) to detect differences between similar modes of load carrying. The following section discusses the use of some perceptual measures, either as a supplemental method or as the sole measure in the study of load carrying.

2.2.2 Perceptual measures in load carrying

Borg (1971) distinguishes among three kinds of physical stress indicators, or three effort continua: perceptual, performance, and physiological responses. Although each one can be used separately in physical work studies, the information they provide is complementary. An example Borg gives is fatigue, which he defines as "a subjective state of a person with both physiological and psychological aspects". Borg (1971) also mentions a rivalry between psychology and physiology when it comes to measuring physical work, and that the three stress indicators have been divided between the two disciplines in a manner depicted in Figure 4.

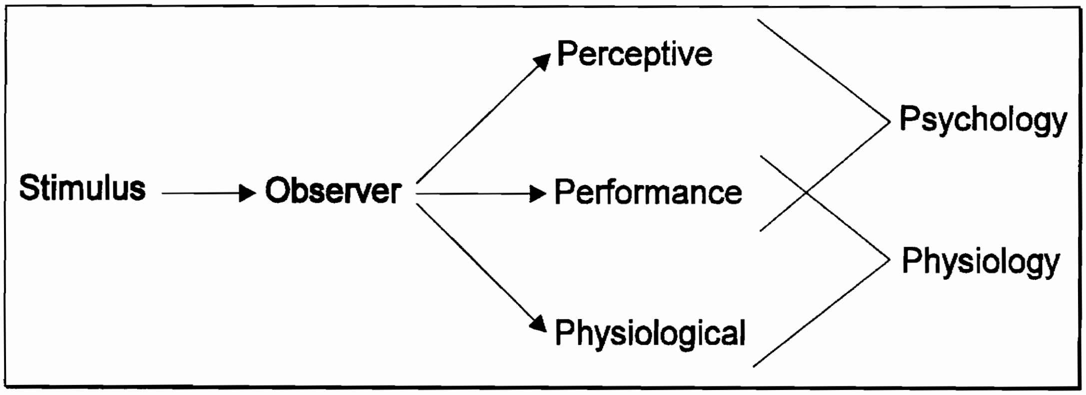

Figure 4. The rivalry between psychology and physiology (adapted from Borg, 1971).

The importance of Borg's paradigm is that it suggests that the measure of muscular work along a single one of the three effort continua will likely provide only part of the total picture. This is certainly supported by some of the research discussed above, where physiological measures remained constant as perceptual measures varied (Legg and Mahanty, 1985; Kirk and Schneider, 1992).

Load carrying studies have, by and large, been studied in the physiological domain. Few studies have incorporated measures in the psychological domain. Most of those that have included both measures used Borg's rating of perceived exertion (RPE) because of its simplicity and its properties which allow interindividual comparisons. The following is a brief description and critique of this rating scale, followed by a description of the method proposed for this study.

2.2.2.1 Borg's ratings of perceived exertion (RPE) scale

Since physiological parameters can be measured both objectively and subjectively, it is quite conceivable that these measures could be correlated. Borg and his colleagues attempted to correlate the two types of measures in the 1950's. A large number of studies were performed to relate physiological measures to people's internal scales of perception of exertion during steady state exercise.

The perception of exertion occurs through a relatively complex mix of sensations originating from the organs of circulation and respiration, the muscles, skin and joints during physical effort (Borg, 1962). Humans have been found to be consistent in their appraisal of these sensations and are able to rate those sensations with respect to their intensity in a reliable manner. Borg distinguished between two types of physical exertion (short duration and relatively long duration) based on the predominance of neural feedback. He notes that during short duration work on a bicycle ergometer, the muscular force is the determining factor; such sensations originate in the skin, muscles, and joints predominantly. During relatively long duration work, there is more stress on the organs of circulation and respiration relative to the musculoskeletal system, and the sensations originate from the cardiorespiratory system predominantly. These observations appear to suggest two distinct sources of sensations: one coming from the muscles and the other from the cardiorespiratory system. These have since been referred to as local and central factors, respectively (Ekblom and Goldbarg, 1971).

Borg's development of a verbally anchored category scale for ratings of perceived exertion (RPE) came to fruition in the early 60's. The most popular scale, i.e. the most widely used in studies involving exertion, is the version of the Borg RPE scale that was published in 1970. Borg's scale relies on the fact that there is a mathematical relationship between sensations in the psychological domain and stimuli in the physical domain. Finding the equation relating the two domains is all that is required to use either one interchangeably. The form of the mathematical equation that best relates the two domains is known as Steven's power law. In the development of his scale, Borg used Steven's power law, relating perception, *P*, to stimulus intensity, *I* in the following form:

$$P = a + c(I - b)^n$$

where *a* represents the basic perceptual noise, *b* is the starting point of the curve, *c* is a conversion factor dependent on the type of effort and *n* is the exponent of the power law.

An exponent of 1.6 was used for the scale since it was found to be most representative of the perception of muscular effort and force. The strategic placement and selection of verbal anchors combined with the correct power law made such that a linear relationship occurred between RPE and work load. Borg decided to link the RPE scale to heart rate by starting the scale at 6, corresponding to a heart rate of 60 beats per minute, and ending it at 20, corresponding to a heart rate of 200 beats per minute (Figure 5). The scale was designed to grow linearly with heart rate, and exertion.

The RPE scale continued to evolve over the years, and Borg proposed a new category scale with ratio properties (Borg, 1982b), intended to be simple and easy to use by untrained test subjects. It uses a familiar 10 point scale, where 0 represents no exertion at all and 10, "extremely strong (almost maximum)" exertion. Because of the smaller number of categories in this new scale, the verbal anchors were changed somewhat from the original scale, to stay in keeping with the power law .

The procedure normally used to collect RPE consists in asking the subjects which of the descriptors corresponds best to on their sensation of the task. The rating can either be collected from overall sensations or from specific areas of the body, such as legs, back, arms, etc. One of the advantages of this scale is that it contains all possible subjective impressions, from zero to maximum. In that sense, it is complete. When this property is combined with linearity over the whole range, this category scale exhibits ratio properties. This means that one can determine whether a given exertion is a fraction or a multiple of another.

Original scale (1970)		New scale (1982)	
6		0	Nothing at all
7	Very, very light	0.5	Extremely weak
8		1	Very weak
9	Very light	2	Weak
10		3	Moderate
11	Fairly light	4	Somewhat strong
12		5	Strong
13	Somewhat hard	6	
14		7	Very strong
15	Hard	8	
16		9	
17	Very hard	10	Extremely strong (almost max.)
18		•	Maximal
19	Very, very hard		
20			

Figure 5. Borg's RPE scales.

The validation of Borg's scale was performed mainly with bicycle ergometer tasks. Borg himself validated the new scale with other sensory modalities, namely perceived sourness (exponent of 0.7) and perceived sweetness (exponent of 1.1). The fit obtained in these modalities, however, was not as impressive as with the bicycle ergometer.

In a set of experiments by Ekblom and Goldbarg (1971), it was found that RPE was higher in arm work than it was for leg work given the same oxygen uptake during exercise. The same was found when comparing bicycling with running or swimming. They proposed a two-factor model of perceived exertion including a set of local factors, such as feelings of strain in the muscles, and a set of central factors, such as cardiorespiratory feelings. They noted that in work involving small muscle groups, the local factors were dominant, whereas in work involving large muscle groups, the perception from central factors were added to that from the local factors.

Goslin and Rorke (1986) pointed out that most of the work performed with the scale has concentrated on cycling or unloaded locomotion, where central factors (cardio-respiratory responses) dominate, and for which the scale was developed. Although the RPE scale has been used in various contexts, very few, if any, validation studies have been made for load carrying, where local factors may dominate (i.e., feelings of strain in the muscles and/or joints) the perception of exertion.

Goslin and Rorke (1986) noted that the "perception of exertion was affected by a complex interaction of many influences" some of which were not necessarily linked closely to physiological factors. In their study, in which they used the Borg (1970) scale (range of 6 to 20), subjects walked at two different speeds and wore a backpack with 0%, 20% or 40% of their body weight. Each walk lasted 10 minutes, and sufficient time was allotted for the subjects to recover fully between trials. The physiological responses, such as oxygen consumption and heart rate, were taken 5 minutes into the walk, whereas the RPE scale was applied 7 minutes into the walk. The results showed that when the subjects were walking on the treadmill unloaded, a proportional increase between RPE and the central responses was observed, in accordance with the developer's intent. As soon as the subjects were wearing loaded backpacks (20% or 40% of their body weight), however, the perception of exertion increased more rapidly than the central responses. This indicates that other factors, such as discomfort perhaps, are entering into the equation and being interpreted as exertion by the subjects.

Goslin and Rorke concluded that, when local factors dominate, the linear relationship between perceived exertion and physiological measures such as heart rate, breaks down. When a load was carried, they stated that "the perception of exertion increased almost twice as much as did the cardiorespiratory measures when compared to the non-loaded walks". This apparent lack of may compromise data analysis and the conclusions drawn from them.

Suggestions have been made to break down the ratings of perceived exertion into their two inferred sources: local and central factors (Pandolf, 1977). It was hoped that by differentiating between these sources, a better understanding of mechanisms which underlie the perception of exertion would evolve. The relative importance of local and central factors was examined in a study of the literature by Pandolf (1982), showing that in some instances one set of factors dominates whereas in others, the other set of factors dominates the overall RPE. It has been proposed that the domination of one source over another depends on the level of stress on their sensory organs and how this dominates awareness in the individual (Horstman, Wiskoff and Robinson, 1979).

Although the dominance of one factor over another may change the linearity of the RPE scale, the overall sensation of exertion remains one where both factors are included. Mihevic (1981) pointed out that the identification of a primary cue of local or central origin appears artificial in view of the *gestalt* nature of the various physiological responses that make up perceived exertion. The multiple sensory inputs of local and central origin are integrated and weighted by the individual in the judgment of exertion (Mihevic, 1981). How this integration is performed remains unclear, which is another reason for not discriminating between the two sources.

It may be concluded that the use of the RPE scale in situations for which it was not designed requires a great deal of care. At first glance, the use of differentiated ratings may appear to be a refinement of the overall rating (or undifferentiated rating), but recent results raise concerns about the interval properties of the scale and the manner in which these ratings would be combined or analyzed. RPE scales may therefore not provide the type of answers required in this experiment. The application of psychophysical methods is therefore proposed for this study.

2.2.2.2 Psychophysics applied to load carrying

Use of the psychophysical approach has been favored by many researchers in manual material handling since the mid 60s (Snook and Irvine, 1967). The reason for this is that, as Mital (1983) pointed out, of the three approaches used in the field of manual materials handling (namely, physiological, biomechanical and psychophysical), the psychophysical method is the only one able to determine the acceptable level at which people will perform frequent and infrequent tasks.

A psychophysical methodology was proposed by Snook (1978) in his study of the maximum acceptable load in industrial manual handling tasks. In this widely quoted paper, Snook describes the method used as "a combination of method of adjustments and tracking". His aim was to determine the acceptability of loads handled by personnel to minimize workplace injuries, particularly in the lower back. Psychophysics was chosen partly because it has been shown that a correlation exists between the risk of lower back injury and the perception of workers as to the degree of physical effort required in their job; "low back injury appeared significantly more frequently in those who believed their work to be harder" (Snook, 1978).

In Snook's experiment, the subjects were instructed to work as hard as they could (on an incentive basis) without "straining themselves, or without becoming unusually tired, weakened, overheated or out of breath". They were allowed to control the weight of the boxes that they had to handle so that they could maintain a comfortable equilibrium between work output and comfort in doing the task. All other test conditions, such as frequency of handling, size, height and distance were controlled. After an initial training period to allow the subjects to acquire experience in monitoring their feelings, the subjects were gradually conditioned to perform the more demanding tasks. New subjects were started with very light or very heavy weights, to encourage them to make the necessary adjustments. To overcome habituation or expectation errors, Snook divided the tasks into two portions, each starting either with a light or heavy load. The loads were increased from light to acceptable by the subjects in one portion of the task, and decreased from heavy to acceptable in the other. If the adjusted weights were within 15% of each other, the two were averaged. Otherwise the test was re-run at another time.

The adjustment period used in this type of method can vary significantly from one study to another in the literature. Snook and Irvine (1967) used an adjustment period of 40 minutes to allow individuals to determine the maximum acceptable weight for an 8 hour work day. Other experimenters used a period of 20 minutes (Legg and Myles, 1981). The validity of using short periods to project acceptability for an 8 hour day has been questioned by Mital (1983). In his study, Mital (1983) found significant differences between the acceptable weights chosen after 25 minutes and those chosen at the end of an 8 hour day. In this case, the psychophysical method provided an overestimate.

Karwowski and Yates (1986) showed that lifting frequency had an effect on the reliability of the prediction, and that for frequencies of less than 6 lifts/min., the weights chosen after 30 minutes did not differ significantly from the weights chosen after 4 hours, whereas at a rate of 12 lifts/min., the final weights were 23% less than chosen after 30 minutes. The conclusion that was reached is that the psychophysical method is not reliable for setting lifting guidelines at frequencies above 6 lifts/min. Examination of the heart rate data appeared to confirm the recommendation of Brouha (1967) which states that heart rate should not exceed 110 beats/min for an 8 hour shift. In the Karwowski and Yates (1986) data, heart rates were around 115 beats/min. after 30 minutes of lifting at a frequency of 6 lifts/min., or near the acceptable limit, but were around 141 beats/min. after 30 minutes of lifting at 12 lifts/min. Based on Brouha's data, this heart rate is clearly above what can be sustained for an 8 hour day. Karwowski and Yates (1986) noted that the subjects' inability to judge the strain of the task at high lifting frequencies may have been due to an increased metabolic demand coupled with a decrease in muscular tension.

Since it is not the object of this study to determine backpack load carrying guidelines for an 8 hour day, but rather to compare two types of backpacks, an adjustment period of 20 minutes should be sufficient, as demonstrated by Legg and Myles (1981). Heart rate, which appears to be a good indicator of where a shift may occur in an individual's ability to perceive work rate, will need to be monitored in this study to ensure that cardiovascular stress does not overwhelm the musculoskeletal sensations of weight.

In a study of discriminability of load heaviness, Karwowski, Shumate, Yates and Pongpatana (1992) concluded that, to obtain reliable results from the psychophysical method, the adjustment process must ensure that each change made to the load must be clearly perceptible. In the task of arranging boxes in order of heaviness, the difference between boxes had to be at least 4 lbs (1.8 kg) for subjects to correctly rank them. The Weber fraction they found for load heaviness over the range of 8.6 to 29.1 kg was between 0.03 and 0.04. The implications for this study are that there should be clearly noticeable changes made during the adjustment period. In the pilot study preceding the experiment, the test subjects were able to perceive the addition or removal of a weight of 1.25 kg (2.5 lbs) fairly reliably, especially as they approached their maximum acceptable load.

3. EXPERIMENT

3.1 Subjects

Four males and four females served as subjects for this experiment. They were recruited from the Reserve Officer's Training Corps (ROTC) at Virginia Tech. Because of their participation in the ROTC program, all subjects had marched with backpacks on a regular basis before the study.

All volunteers were screened for any known medical, back or musculoskeletal problem by means of a questionnaire (Appendix A). Although two of the subjects reported having had back pain within the last year, they were not suffering from any pain at the time of the experiment. None of the volunteers reported any physical impairment “worth noting”. The number of subjects of each sex assessing their physical condition as “fair”, “good” or “excellent” is reported in Table 1.

Age, body weight, stature and back length (surface distance along the spine from the cervicale to the posterior waist landmark) are reported in Table 1. Each subject filled out an informed consent form prior to the study (Appendix C) and was asked to refrain from vigorous activity on the days of the experimental sessions.

Table 1. Subjects.

		Age	Weight (kg)	Stature (cm)	Back length (cm)	Physical condition		
						Fair	Good	Excellent
Males (n=4)	Avg.	21.0	77.0	177.3	50.8	1	2	1
	S.D.	0.0	3.1	5.0	2.7			
Females (n=4)	Avg.	26.0	59.4	164.3	44.1		1	3
	S.D.	9.3	10.3	3.4	3.8			

3.2 Apparatus

A DP Concourse (Series 10.6 MI) motorized treadmill was used in the experiment. This treadmill featured a 2 hp motor, digital control of the motor speed to within 0.1 mph, and an ear plethysmograph for heart rate readout.

A Northern Digital WATSMART (version 2.7) three-dimensional motion analysis system was used to record the posture of subjects while standing and walking with and without a loaded backpack. The WATSMART system included infrared light emitting diodes, two infrared cameras interfaced with a GRID 386 personal computer, and a calibration frame. The two cameras were used to track the three markers located on the subjects. The experimental layout is shown in Figure 6.

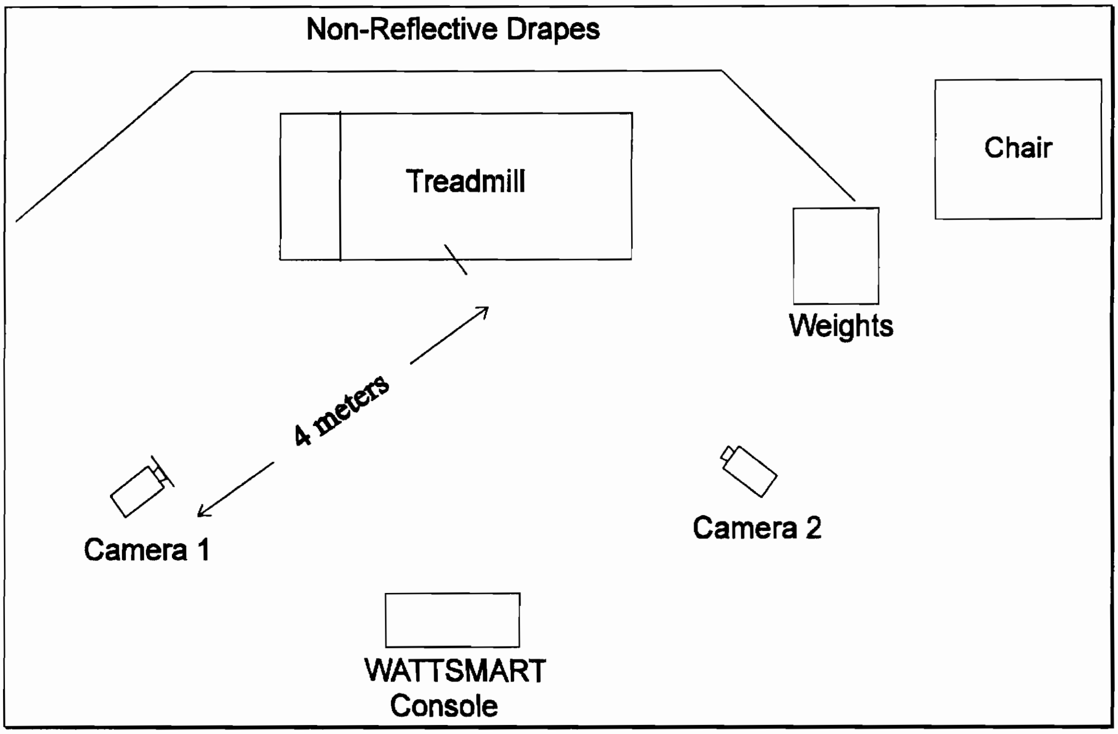

Figure 6. Experimental set-up.

Two backpack types were used: an internal and an external-frame backpack. The Minaret™ internal-frame backpack by Gregory® was selected on the basis of its well designed and padded shoulder straps and waist belt. This backpack is shown in Figure 7. The frame consists of a combination of 1 mm thick high density polyethylene sheet supported by an S-shaped central aluminum stay. The load is distributed to the user's body by the Flo-Form™ waist belt, shoulder harness and backpanel. The backpanel consists of a "sculpted" foam pad with molded air channels, which are intended to promote ventilation and evaporation of perspiration. The molded air channels are approximately one centimeter deep and wide, and criss-cross the backpanel at about 5 cm intervals and 30 degree angle from horizontal. This pattern of channels leaves a series of eight contact surfaces either side of the backpanel that are 5x10 cm^2 and four in the middle that are 5x5 cm^2. The manufacturer of this backpack claims that load bearing can be shifted between the hips, shoulders and back, to provide relief from local muscle fatigue, and therefore improve comfort.

The internal backpack used in this study suffered from a lack of rigidity which caused it to deform when loaded. This characteristic was first noticed during the pilot study. Pilot study test subjects complained that the load felt like it was "falling off" and that this was causing a problem. It was determined that this phenomenon was caused by the deflection of the plastic back panel support each side of the central aluminum stay. This was counteracted by the addition of a central supporting strap directly connected to the top of the central aluminum stay.

The external-backpack configuration used during this study is shown in Figure 8. It consists of the Canadian military backpack (1982 pattern) slightly modified for the purposes of the experiment. The modification consisted in the lowering of the pack from its normal high position to the low position depicted in Figure 8; all the other elements were the same. This backpack basically consists of a contoured wire frame onto which the suspension system (hip belt and shoulder harness) and pack are added. The hip belt is unpadded.

Figure 7. Minaret^{TM} backpack.

Figure 8. External-frame backpack.

Stackable rectangular steel weights measuring 11 cm by 30 cm by 2.5 cm thick were used, each weighing 4.54 kg (10 lbs). Round 2.27 kg (5 lbs) and 1.14 kg (2.5 lbs) weights were used for the finer adjustments of the backpack load.

A poster was prepared which included a summary of the steps involved in the experiment as well as a reminder of the instructions to the subjects. In addition, the seven-point Corlett and Bishop (1976) scale and the body diagram, containing numbered body parts, were also contained on the poster. The poster information is presented in Appendix D.

3.3 Marker placement

The diode markers were placed at the ankle, trochanter, and neck, as shown in Figure 9. The landmarks defined in NASA (1978) were used for the location of the ankle and trochanter, whereas the neck marker was aligned with the subject's earlobe.

To avoid displacement of the markers during physical activity, the diodes were secured to a 2.5 cm wide nylon/rubber woven elastic which was then wrapped around like a belt. These elastics were placed around the neck, waist and ankle of the subjects in such a manner as to be firmly positioned without causing discomfort. Movement of the waist marker was noticed during the pilot study, and as an extra precaution, a paper clip was used to secure the elastic to the subject's shorts. This procedure resulted in improvement, however, a small amount of movement remained for some subjects.

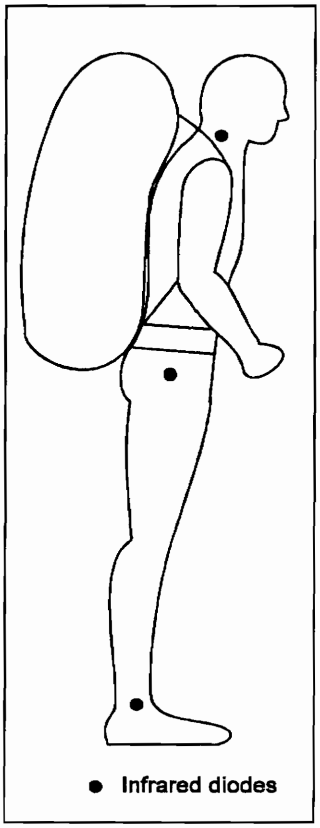

Figure 9. Placement of infrared markers.

3.4 Experimental task

The subjects were required to walk on a treadmill with a loaded backpack for 15 minutes at a time. During this period, they were asked to determine what they would consider to be the maximum acceptable load they would carry on a one day trek. Based on the test conditions, they were expected to request weight increases or decreases as they attempted to arrive at a load they would deem to be not too heavy nor too light, but "just right". At the end of the 15 minute period they were asked to provide ratings of discomfort and to identify the body areas of greatest discomfort.

3.5 Load placement

To ensure that the load position was the same in all test conditions, both backpacks were carefully measured and adjusted to each subject. The cross-section of each backpack was plotted in the "as worn" position, as shown in Figure 10. The common load positions for each backpack frame were obtained from this drawing. The vertical positions were selected such that the center of gravity of the load would be located roughly one third of the way up (for the low condition) and two thirds of the way up (for the high condition) from the bottom of the pack.

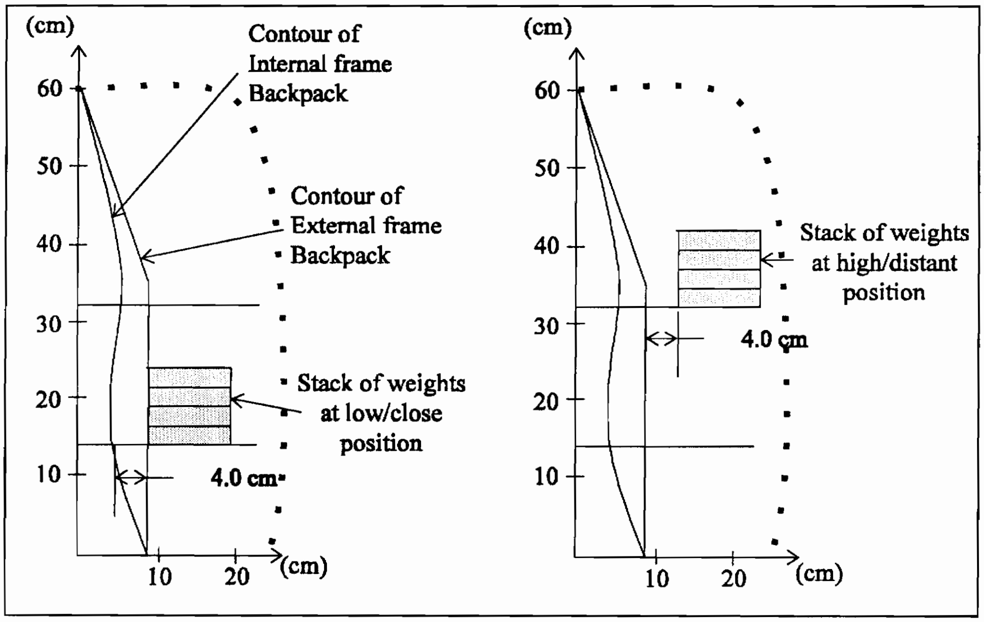

Figure 10. Positioning of the load relative to each backpack.

Since it was not possible to position the load any closer to the body than the external-frame would allow, a 4.0 cm spacer was added to the internal-frame backpack in order to obtain a common load position. Therefore, the lowest common denominator in terms of closeness to the body (the “close” condition) was the closest position allowed by the external-frame backpack. Given that the horizontal distance separating the two types of packs was 4.0 cm at the two heights, this distance was selected as the difference between the "close" and "distant" levels of this variable. Thus, a 4 cm spacer was added to the external-frame backpack and an 8 cm spacer was added to the internal-frame backpack in order to accomplish the “distant” load position level. The two extreme positions, namely low/close and high/distant are depicted in Figure 10.

3.6 Experimental design

A within-subject experimental design was selected because of the nature of the study and the large inter-subject variability expected. Each subject performed the experimental task twice at each of 8 different conditions, for a total of 16 tests. The eight conditions are listed in Table 2. To control for bias, and to encourage subjects to adjust the load, all subjects were required to start either with a light load, or a heavy load. The starting loads were based on the body weight of the participants and were typically between 15% and 20% for the light load (due to rounding to the nearest 2.27 kg (5 lbs)) and around 35% for the heavy load. For the test to be “successful”, that is to be included in the data set, the load obtained at the end of the 15 minute adjustment period after increasing the load had to agree to within 15% of that obtained after decreasing the load. When not successful, the test condition was repeated until there was good agreement between the two series (ascending and descending). Use of this rule helped to detect judgment inconsistencies on the part of the test subject and increase the reliability of the results.

Table 2. Treatment conditions.

	Treatment	Pack Type	Horizontal Load Position	Vertical Load Position
Block 1	A	Internal	Close	Low
	B	External	Distant	Low
	C	External	Close	High
	D	Internal	Distant	High
Block 2	E	External	Close	Low
	F	Internal	Distant	Low
	G	Internal	Close	High
	H	External	Distant	High

Because of the large number of tests and their duration, the testing sessions were divided into two sessions of 3.5 hours each. The subjects were assigned to the "Day 1" or "Day 2" schedules (Table 3) in accordance with the principles of simple blocking. The defining relationship used was:

$$x_1 + x_2 + x_3 = 0,\ 1\ \textit{(Modulo 2)}$$

In other words, the 3-way interaction was selected as the effect to be confounded with Blocks, since it was of no interest in this study. Half of the males and half of the females were assigned to start with the first block and the other half with the second block. Subjects were randomly selected for each category. Presentation order was controlled for each block using a balanced Latin square to counteract the effects of fatigue and/or learning during the session. The assignment of treatments was as shown in Table 3.

Table 3. Treatment presentation order for subjects on days 1 and 2.

Subject	Gender	Treatment condition presentation order							
		Day 1				Day 2			
1	M	A	B	D	C	E	F	H	G
2	M	B	C	A	D	F	G	E	H
3	F	C	D	B	A	G	H	F	E
4	F	D	A	C	B	H	E	G	F
5	M	E	F	H	G	A	B	D	C
6	M	F	G	E	H	B	C	A	D
7	F	G	H	F	E	C	D	B	A
8	F	H	E	G	F	D	A	C	B

3.6.1 Independent variables

The variables under investigation were as follows:

1. Pack type (P), (2 levels): Two types of backpacks were used: "internal" and "external". The two levels of this variable are based on macroscopic differences between the internal- and external-frame backpacks used in this study. The external-frame backpack is characterized by its more conventional shoulder straps and unpadded hip belt, whereas the internal-frame backpack is characterized by more contoured shoulder straps, a padded hip belt and the fact that the contact area is not only the shoulders and hips but also the back.

2. Horizontal Load Position (HPos), (2 levels): The horizontal load position refers to the offset distance of the load perpendicular to the plane of the back. This distance was modified through the use of Styrofoam spacers, to separate the load from the back. The difference between the two levels, i.e. "close" and "distant", was 4.0 cm, based on the measured differences between the two types of backpacks used in this study (Figure 10).

3. Vertical Load Position (VPos), (2 levels): The vertical load position refers to the distance of the load parallel to the back, relative to the hip belt. The two levels were “low” placement of the load (the lower one-third of the pack) and “high” placement (roughly two-thirds up from the bottom of the pack), as described earlier. Both positions were measured from the hip belt, and were the same regardless of the pack's physical dimensions.

3.6.2 Dependent variables

1. Maximum Acceptable Load (MAL): This measure is the average of the final load selected by individuals after increasing or decreasing the starting loads to meet their subjective "comfort level".

2. Trunk Angle: The static and dynamic trunk angles were calculated from the data collected on markers 1 and 2 (neck and trochanter landmark), using the coordinates in the sagittal plane (x-z plane). Two sets of static and dynamic angles were collected: one in the unloaded condition, at the beginning of the experiment, and one after the MAL was determined, at the end.

   Figure 11 depicts the way in which the static trunk angles were calculated. The marker positions are shown for both the static reference condition, i.e. standing still without any load in the backpack, and once the MAL has been determined. The data analysis considered the absolute trunk angles (static and dynamic) once the final load was selected, and the difference in trunk angles due to the addition of the load. The coordinate system is shown in Figure 12.

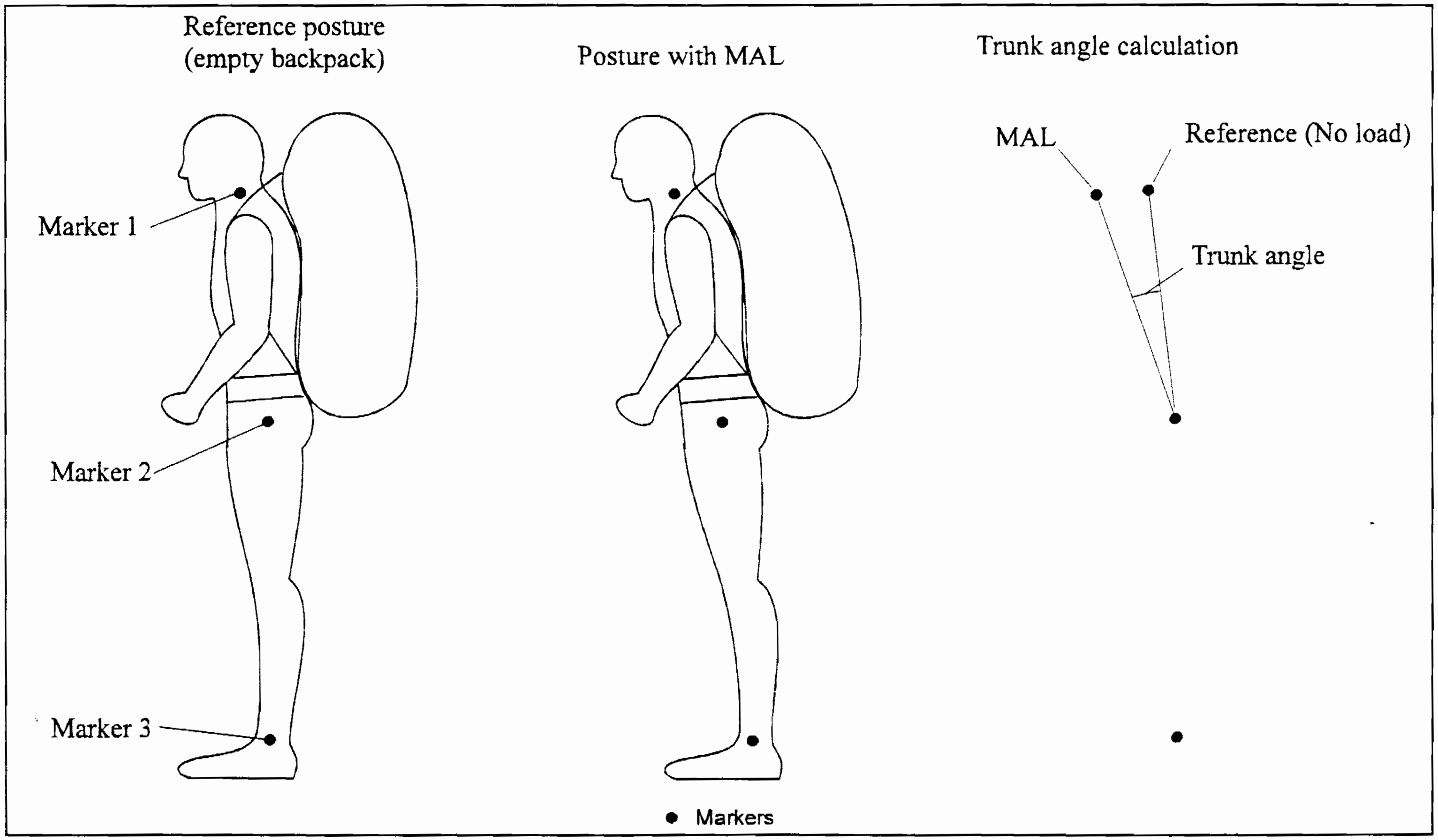

Figure 11. Marker positions for trunk angle calculations.

The dynamic trunk angles were also recorded during a reference condition (walking without any load) and during the test condition once the MAL had been determined. A representation of the dynamic marker positions for the unloaded and loaded positions is shown in Figure 12. The average angle over the 10 second sampling period was calculated for both the reference and test conditions in the same way as for the static angles, i.e. using the instantaneous angle for each of the 200 recorded marker positions. The difference between these averages was used in the analysis of the results.

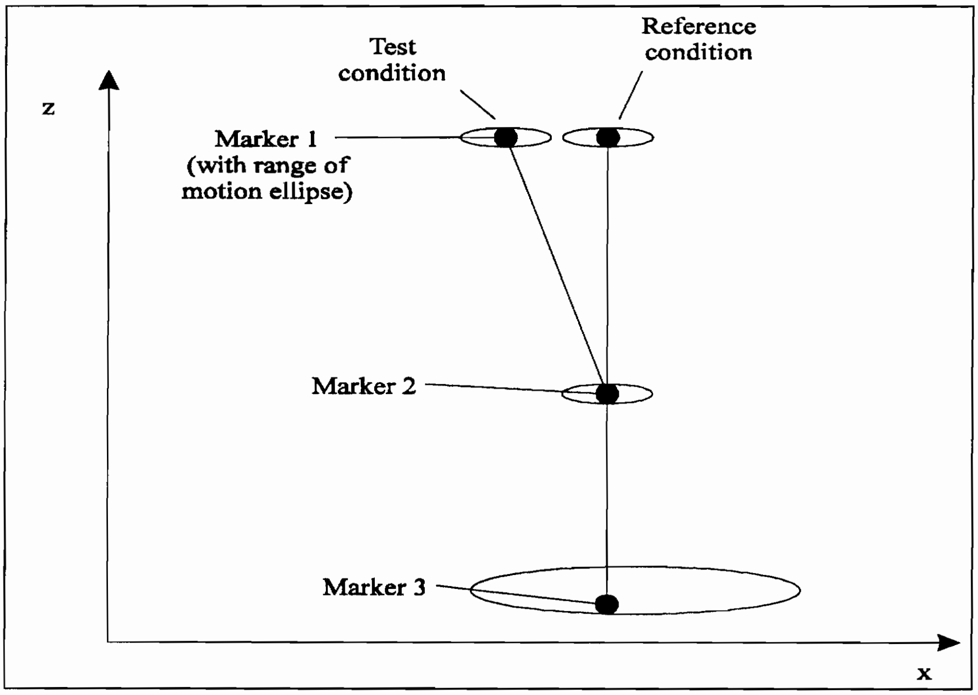

Figure 12. Marker positions for dynamic trunk angle calculations.

3. Cadence (C): Cadence, or stride rate, was also calculated from the WATSMART data collected. Marker 3's (ankles) positional cycles were used

as the basis of the calculation. Cadence was calculated for the unloaded and final load conditions to observe any change in stride rate between the two.

4 Overall discomfort ratings (ODR): Overall discomfort ratings were obtained at the end of the 15 minute walking period.

5 Body part discomfort (BPD): the body parts of most discomfort were identified immediately following the ODR, as per Corlett and Bishop (1976).

3.7 Experimental Protocol

As stated earlier, the experimental sessions took approximately 3½ hours for each day. In a preliminary session, the subjects were asked to fill out the health questionnaire (Appendix A) . The subjects were weighed and measured as per Table 1. The overall goal and procedures of the experiment were explained and a copy of Appendix B was given to each subject to take home.

At the start of the first test session, each participant was asked to read and sign the informed consent form (Appendix C). The subjects were reminded of the overall goal and procedures of the experiment, and were instructed on how to mount and dismount the treadmill. The safety features of this equipment were shown. The subjects were then given a chance to experiment with the treadmill until they felt ready to begin the experiment.

The subjects were then fitted with the 3 markers required for the operation of the WATSMART system. The experimenter located the bony landmarks of the ankle and trochanter and attached the three diodes as per section 3.3. Next, the subjects were fitted with the appropriate empty backpack, at which point they were asked to step onto the treadmill and position themselves to be in view of both infrared cameras. This position was designated by two tape marks placed on the body of the treadmill. The position of the diodes was recorded statically for 10 seconds. The subjects then followed the procedure to ramp up the treadmill speed and proceeded to walk normally. A moderate walking pace of 4.7 km/h (2.8 mph) was used for all experiments based on psychophysically established limits of acceptable walking speed while carrying loads (Snook, 1976). The marker positions were then recorded for 10 seconds.

At this point, the subjects' backpacks were loaded with the starting load. They were told that there were no restrictions on when to adjust the load, and were given their first opportunity immediately after the weights were loaded, before even starting the treadmill. During the first few tests, the subjects were reminded of the verbal descriptors for load change (i.e. "large amount", "medium amount" and "little amount") at five minute intervals. The experimenter encouraged making adjustments by saying: “it is not possible to make too many adjustments, but you can make too few”. The weight adjustments were performed as the subjects were walking, without any difficulty. The procedure for adjustment of the load was repeated as often as necessary.

Heart rates were monitored both as a precaution and to ascertain that the subjects were following the instructions, i.e. that they were not overexerting themselves. Their pulse rates were not allowed to exceed 140 beats per minute, because doing so has been shown to result in unsuitable load selection (Karwowski and Yates, 1986). A heart rate between 110 or 115 beats per minute has been shown to be sustainable for an 8 hour work day (Brouha 1967), and was used as a benchmark to judge whether the subjects were following the instructions.

At the 13 minute mark, the subjects were given their last chance to make a change to the load. At that point, the marker positions were recorded during a 10 second period. The subjects were asked to stop the treadmill and stand still, in equilibrium, as in the first part of the test. This static position was recorded during a 10 second period as well. The subjects were then asked to provide an overall discomfort rating on a seven point scale and to identify the regions of highest discomfort using the body part chart provided (see Appendix D for the details). The final backpack load was recorded by the experimenter, and the weights were removed. The subjects were given 5 minutes to rest and drink water before the next session would begin. This amount of time was more than sufficient given the fitness level of the subjects involved and the relatively low rate of exertion. At the half way mark, i.e. after 4 of the 8 tests for the day were completed, the subjects were given an opportunity to sit during their 5 minute break. Table 4 shows the timing of the various activities taking place during one trial.

Table 4. Schedule of events during one trial.

Time (min.)	Subject activity	Experimenter
-2	Stand without load	Record posture
-1	Walk without load	Record posture
0		Add starting load
1	Walk and monitor body sensations. Request load adjustment as required.	Adjust load as required
2		Note heart rate
3		
4		
5		Reminder to adjust load
6		
7		
8		
9		
10		Reminder to adjust load
11		
12		
13	Last chance to make a load change	
14		
15	End of walk	Record dynamic posture
16	Stand still w/ load	Record static posture
17	Give discomfort ratings	Record MAL, ratings
18		Remove load
19	Rest	Prepare new condition
20		
21		
22		
23		
24	New test condition.	
25	Ready to start again	

4. RESULTS

4.1 WATSMART data transformation

4.1.1 Marker measurement accuracy

The calibration of the cameras was performed in three steps. The calibration frame, which was 50 cm wide by 55 cm deep and 63 cm high, was first placed 120 cm above the treadmill, where the location of the neck marker was expected to be. The WATSMART calibration routine was then executed. The frame was then repositioned at heights of 60 cm and 0 cm above the treadmill to complete the calibration routine. The three calibrated volumes were then combined into an overall volume through an iterative technique used by the WATSMART system. From the combination of the data came an overall estimate of measurement accuracy, which was an average of 10.93 ± 0.60 mm for all of the experiments performed. This may seem high at first glance, but in terms of trunk angles, which was the ultimate reason for the use of the WATSMART system, this represents less than a one degree error based on the distance between the trochanter and neck markers.

4.1.2 Data transformations

The three-dimensional position data coming from the WATSMART system was converted into an ASCII file from within the WATSMART software using the printing option in the Display module. This file was then imported into the Microsoft® Excel 4.0 program from which all calculations and transformations were effected. A macro program was written to handle the data reduction process, which dealt with the automatic opening of the files and the calculation of trunk angles, cadence, and the creation of graphs and summary data sheets suitable for further statistical analysis. The flowchart of this macro is shown in Figure 13.

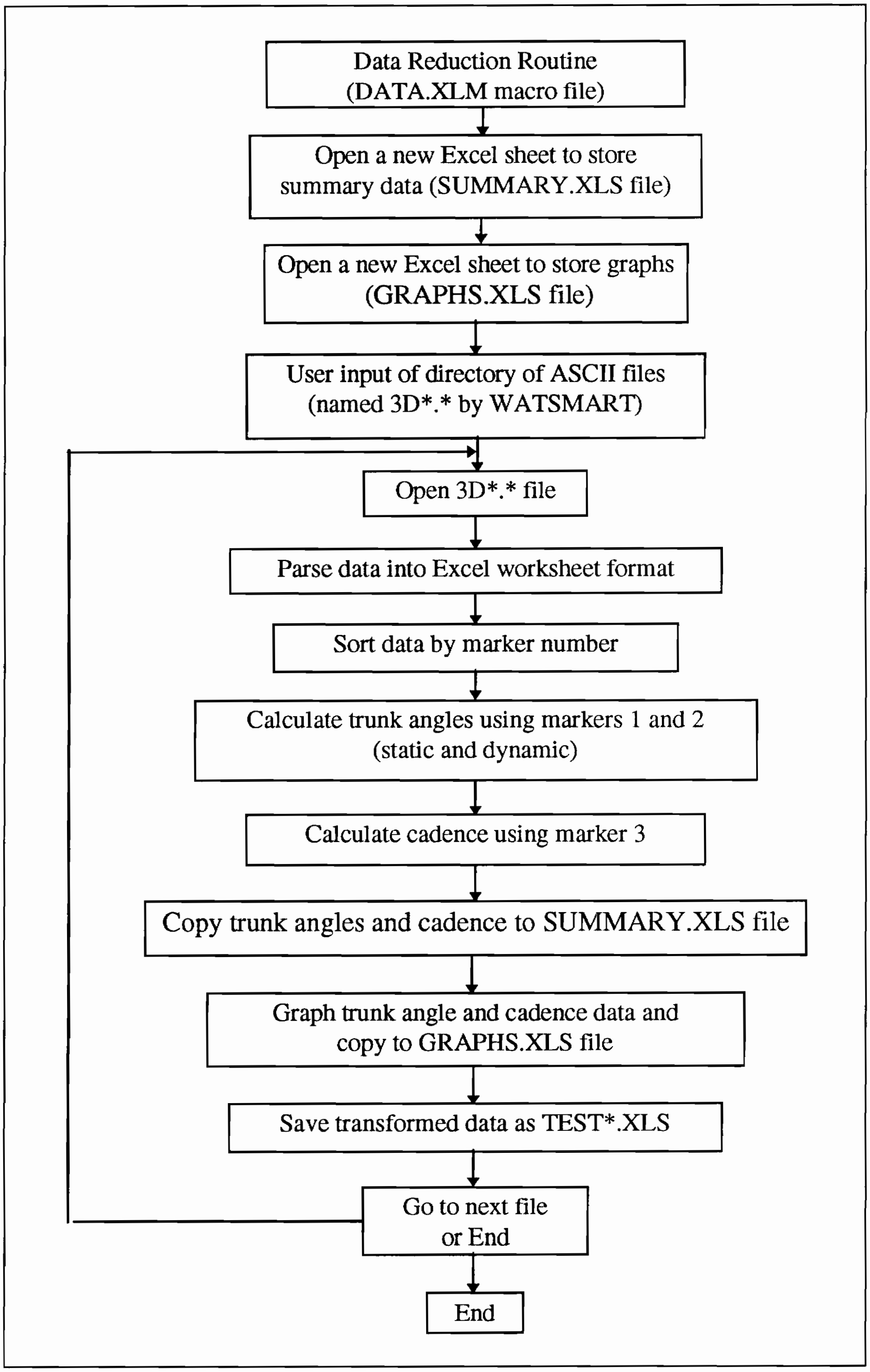

Figure 13. Flowchart of data transformation macro.

4.1.2.1 Trunk angle calculations.

The trunk angles were calculated in the sagittal plane, which corresponded with the x and z coordinates of the WATSMART system. They were calculated as follows for each of the 200 points recorded by the cameras (10 seconds of recording at 20 Hz):

$$Trunk\ angle = \arctan\left(\frac{x_2 - x_1}{z_2 - z_1}\right)$$

where x_1 and x_2 are the x-coordinates of markers 1 and 2, and z_1 and z_2 are their z-coordinates

Typical plots of the instantaneous static and dynamic trunk angles are shown in Figures 14 and 15.

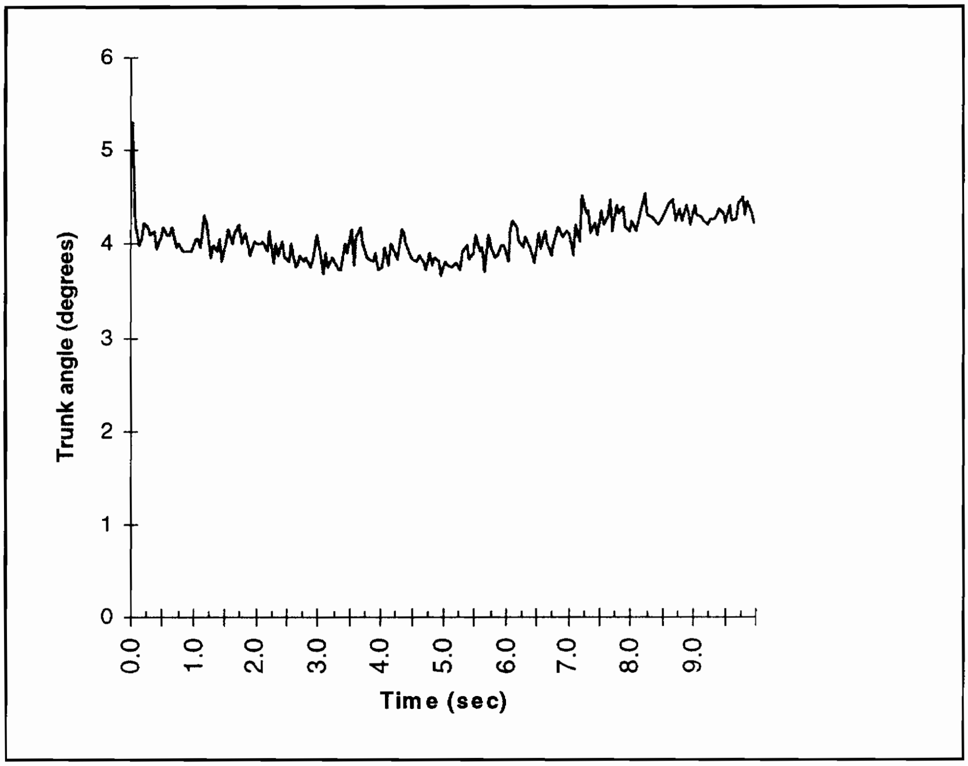

Figure 14. Static trunk angle over time.

The instantaneous trunk angles were then averaged, over the middle 9.5 seconds of the 10 second data collection period (that is, ignoring 0.25 seconds at the beginning and at the end) to avoid biasing the result due to data inconsistencies that frequently occur during the switching on and off of the WATSMART data collection mode.

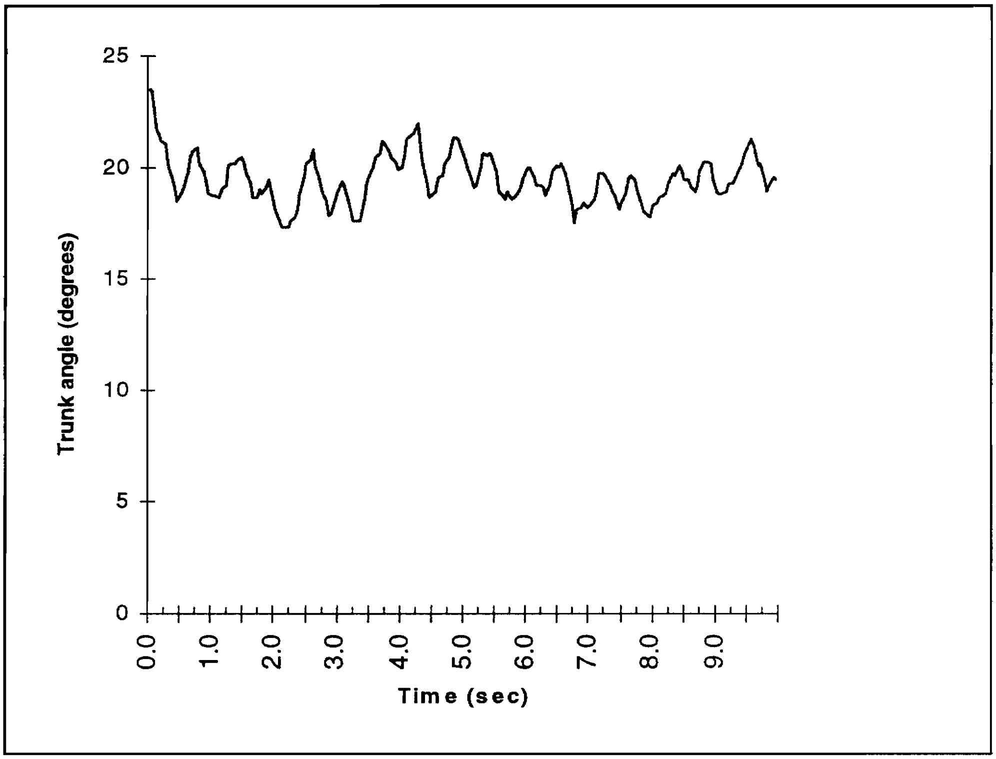

Figure 15. Dynamic trunk angle over time.

4.1.2.2 Cadence calculations.

Cadence, or stride frequency, was also calculated from the WATSMART data, using the x-coordinate data of Marker 3. A typical plot of the data collected is shown in Figure 16. The macro routine was designed to locate the peaks and note the time of each. The number of cycles was averaged over time, yielding the number of cycles/second of the left leg. This number was multiplied by two to obtain the cadence.

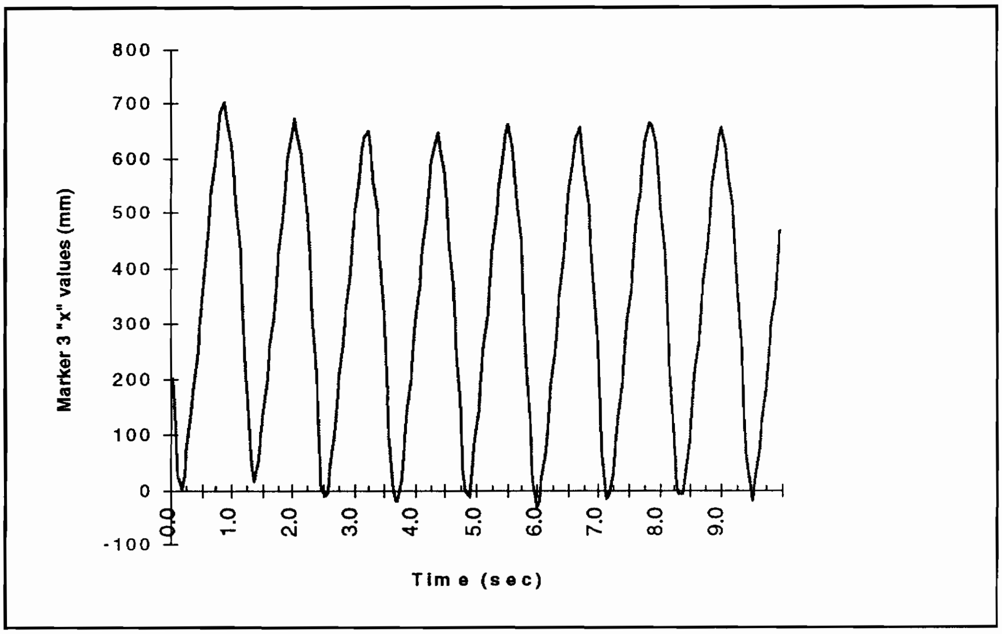

Figure 16. Typical plot of x-coordinate for the ankle marker (#3).

4.2 Maximum acceptable load (MAL).

The maximum acceptable load (MAL) which was carried under each condition, consisted of the weight of the particular pack condition and the load added during the test. Two sets of figures were obtained for each condition: one for the ascending series (starting with a light load and increasing until the MAL was obtained) and one for the descending series (starting with a heavy load and decreasing until the MAL was obtained). The overall results are listed in Table 5. On average, the ascending and descending series final loads were within 5% of each other, demonstrating a high degree of consistency in the subjects' psychophysical assessments of the load. On a percentage of weight basis, subjects tended to feel comfortable carrying approximately 22% of their weight. The box and whisker plot of Figure 17 gives a summary of the results in terms of the extremes of final load (the whiskers), the interquartile range (i.e. the 25th to 75th percentile loads enclosed by the box) and the median of the final load (the line inside the box) selected.

Table 5. Average static trunk angle induced by the final load.

		MAX. ACCEPTABLE LOAD (lbs)							
		Internal frame				External frame			
		Close		Distanced		Close		Distanced	
Subject	Series	Low	High	Low	High	Low	High	Low	High
1	Ascending	45.75	36	35.75	41	42.75	40.5	42.75	38
	Descending	50.75	36	35.75	38.5	37.75	45.5	42.75	38
2	Ascending	35.75	46	38.25	31	42.75	53	47.75	38
	Descending	35.75	38.5	35.75	31	37.75	38	47.75	38
3	Ascending	30.75	23.5	20.75	31	25.25	25.5	32.75	28
	Descending	30.75	23.5	23.25	31	25.25	28	32.75	28
4	Ascending	33.25	31	30.75	31	27.75	35.5	32.75	28
	Descending	35.75	33.5	30.75	33.5	30.25	38	35.25	30.5
5	Ascending	45.75	43.5	38.25	51	37.75	48	47.75	40.5
	Descending	50.75	46	40.75	46	40.25	48	45.25	43
6	Ascending	28.25	18.5	18.25	26	22.75	30.5	30.25	23
	Descending	25.75	21	18.25	31	22.75	30.5	30.25	23
7	Ascending	33.25	31	25.75	28.5	35.25	30.5	30.25	30.5
	Descending	30.75	31	25.75	28.5	35.25	30.5	30.25	33
8	Ascending	20.75	21	20.75	18.5	22.75	25.5	22.75	25.5
	Descending	23.25	18.5	20.75	21	22.75	25.5	22.75	23

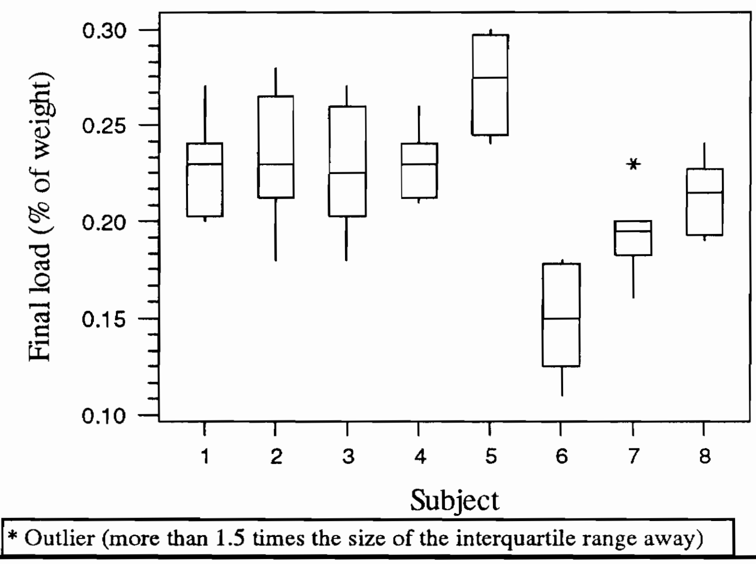

Figure 17. Final load selection as a percentage of body weight.

A within-subjects analysis of variance (ANOVA) was performed on the average of the ascending and descending series MAL. The results of this analysis are shown in Table 6. Statistical significance ($\alpha = 0.05$) was found for Blocks (days on which the tests were carried out), Pack type and the interaction of Pack type with Horizontal Load Position. The Pack main effect and the Pack x HPos interaction are plotted in Figures 18 and 19 respectively. Figure 18 clearly shows that the use of the internal-frame backpack (Pack 1) resulted in lower loads being carried than when the external-frame backpack was used (Pack 2). It is also clear that the horizontal placement of the load further away from the back had a pronounced effect on subjects wearing the internal-frame backpack whereas it had no effect while wearing the external-frame pack. Paired comparisons of the components of the Pack x HPos interaction were performed using Tukey's Honestly Significant Difference Test at the 0.05 probability level. The results showed that the means designated by A in Figure 19 differed significantly from the mean designated by B.

Table 6. ANOVA of Maximum Acceptable Load.

Factors	*df*	*SS*	*MS*	*F*	*p*
Between-subjects					
S	7	3623.61	517.66		
Within-subjects					
Blocks (Pack x HPos x VPos)	1	239.28	239.28	11.11	0.013*
Blocks x S (S x Pack x HPos x	7	150.76	21.54		
Pack	1	66.52	66.52	5.83	0.046*
S x Pack	7	79.86	11.41		
HPos	1	20.53	20.53	3.92	0.088
S x HPos	7	36.69	5.24		
VPos	1	0.05	0.05	0.01	0.915
S x VPos	7	27.71	3.96		
Pack x HPos	1	20.53	20.53	9.21	0.019*
S x Pack x HPos	7	15.60	2.23		
Pack x VPos	1	0.22	0.22	0.07	0.795
S x Pack x VPos	7	21.07	3.01		
HPos x VPos	1	0.61	0.61	0.03	0.869
S x HPos x VPos	7	144.90	20.70		
Total	63	4447.94			

* $p < 0.05$

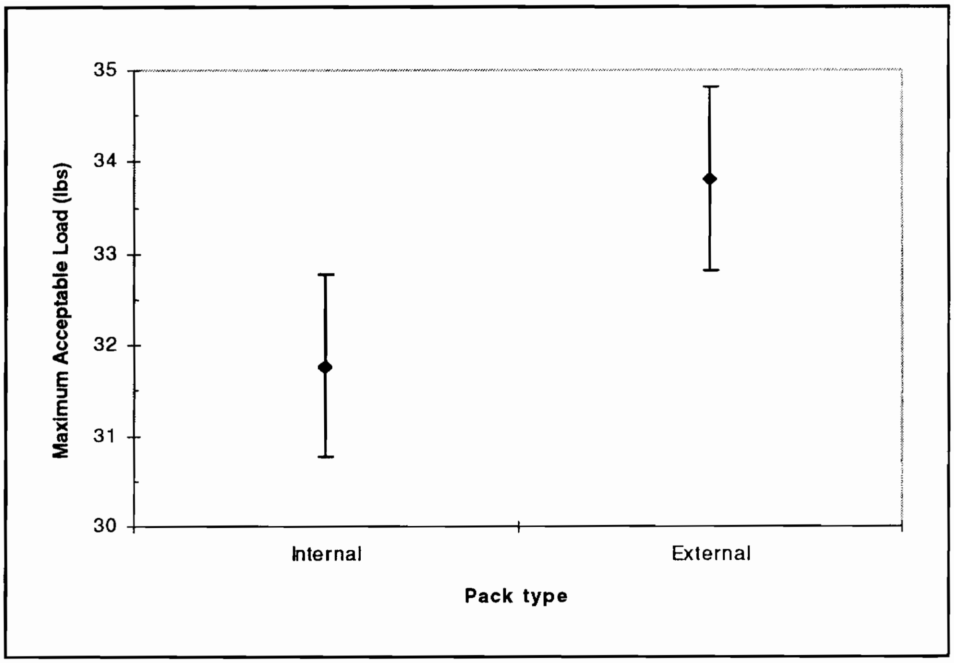

Figure 18. The effect of pack type on load acceptability (means and standard error shown).

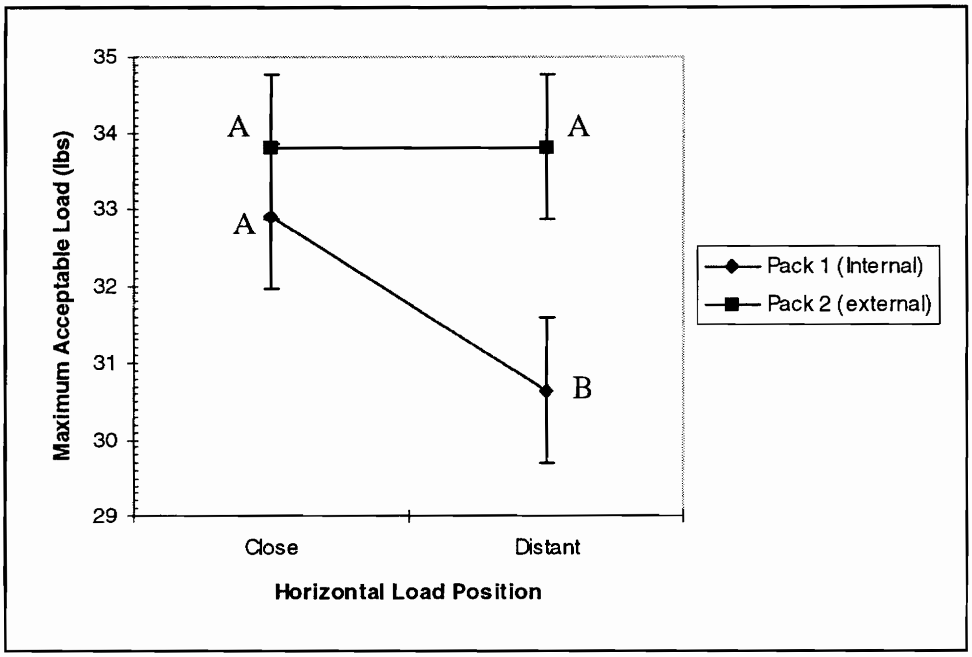

Figure 19. The effect of pack type and horizontal position on load acceptability (means and standard error shown).

4.3 Trunk angle

For each test condition, static and dynamic trunk angles were recorded for the reference conditions, and again once the final load had been selected (at the 13 minute mark). The reference condition consisted of standing and walking with the backpack and load positioning accessories, but without any of the steel weights. The data was analyzed in two ways:

i) using the absolute trunk angles, which were the average of the ascending and descending series trunk angles measured once the final load had been selected, and

ii) using the differential trunk angles, which was the trunk angle induced by the addition of the MAL in the backpack, i.e. average angle with final load minus average angle without load.

The average static and dynamic trunk angles obtained during this study are shown in Tables 7 through 14. Each table of results is followed by a within-subject analysis of variance (ANOVA) which was performed to investigate the possible effects of the test conditions on the trunk angles.

Analysis of the results listed in Table 7 (absolute static trunk angles) are shown in Table 8, where a significant effect of Pack type ($p = 0.007$) can be seen. A plot of this effect (Figure 20) shows that the subjects had a more upright static posture when wearing the loaded internal-frame backpack compared to when they were wearing the loaded external-frame backpack. The figure depicts means and their 95% confidence limits.

The absolute dynamic trunk angle results are listed in Table 9. The analysis of variance (Table 10) showed two significant main effects: Pack type ($p = 0.015$) and

Horizontal load position (p = 0.030). Again, the plot of trunk angle versus Pack type (Figure 21) shows that the subjects remained more upright when walking with the loaded internal-frame backpack than when walking with the loaded external-frame backpack. Figure 22 shows that subjects tended to lean forward more when the load was placed farther away from the back, which was predicted in section 2.1.1 on biomechanical aspects of backpack load carrying.

The differential static trunk angles (Table 11) appeared unaffected by the test conditions, as none of the main effects or two-way interactions was significant (Table 12). A significant difference was found in Blocks (p = 0.002), however, which represents the days on which the tests were conducted.

The analysis of differential dynamic trunk angles (Table 14), on the other hand, revealed a significant effect of vertical load position (p = 0.05). Figure 23 shows that subjects tended to walk more upright when the load was carried higher up. As in the case of the static differential trunk angle, the day (Blocks) on which the test was performed, i.e. whether it was Day1 or Day2, appears to have had a significant effect (p = 0.03) on the average trunk angles.

Table 7. Average static trunk angles (degrees) with final load.

	Internal frame				External frame			
	Close		Distanced		Close		Distanced	
Subject	Low	High	Low	High	Low	High	Low	High
1	12.73	9.66	10.88	13.29	15.78	15.54	8.21	12.01
2	7.28	6.66	7.58	8.92	5.88	8.84	12.21	5.59
3	8.70	6.64	10.79	8.71	10.66	8.80	8.46	9.60
4	0.76	5.22	4.78	4.01	3.80	5.57	7.10	8.62
5	9.49	6.45	4.68	7.19	4.23	7.56	10.08	7.57
6	6.61	10.47	9.56	8.53	10.81	8.32	8.93	10.97
7	13.46	4.65	11.90	13.04	10.30	13.43	13.49	7.04
8	4.79	0.99	1.61	6.23	2.84	10.53	4.26	4.10

Table 8. ANOVA of static trunk angles.

Factors	*df*	*SS*	*MS*	*F*	*p*
Within-subjects					
S	7	412.6	58.9		
Between-subjects					
Blocks (Pack x HPos x VPos)	1	28.6	28.6	1.98	0.202
Blocks x S (S x Pack x HPos x VPos)	7	100.7	14.4		
Pack	1	19.0	19.0	14.07	0.007*
S x Pack	7	9.5	1.4		
HPos	1	2.4	2.4	0.62	0.464
S x HPos	7	27.4	3.9		
VPos	1	0.1	0.1	0.01	0.911
S x VPos	7	35.6	5.1		
Pack x HPos	1	7.4	7.4	1.04	0.342
S x Pack x HPos	7	49.9	7.1		
Pack x VPos	1	2.2	2.2	1.17	0.315
S x Pack x VPos	7	13.4	1.9		
HPos x VPos	1	0.0	0.0	0.00	0.984
S x HPos x VPos	7	23.5	3.4		
Total	63	732.3			

* $p < 0.05$

Table 9. Average dynamic trunk angles (degrees) with final load.

	Internal frame				External frame			
	Close		Distanced		Close		Distanced	
Subject	Low	High	Low	High	Low	High	Low	High
1	17.87	14.01	17.91	17.52	19.18	21.31	20.70	19.34
2	15.50	15.56	15.09	17.80	15.15	17.08	18.12	13.85
3	18.95	16.64	21.13	15.99	22.67	17.71	18.38	20.15
4	7.43	11.12	10.28	10.85	10.70	11.85	13.44	14.58
5	16.07	18.93	16.91	14.85	15.66	15.41	17.13	19.38
6	10.38	14.16	14.04	12.45	15.19	12.44	13.48	15.91
7	15.43	5.61	13.98	15.28	13.90	13.77	15.72	8.12
8	8.90	6.29	7.22	11.90	9.92	17.74	12.09	10.72

Table 10. ANOVA of dynamic trunk angles.

Factors	*df*	*SS*	*MS*	*F*	*p*
Within-subjects					
S	7	578.1	82.6		
Between-subjects					
Blocks (Pack x HPos x VPos)	1	6.4	6.4	0.37	0.567
Blocks x S (S x Pack x HPos x VPos)	7	120.0	17.1		
Pack	1	46.8	46.8	10.22	0.015*
S x Pack	7	32.1	4.6		
HPos	1	7.4	7.4	7.35	0.030*
S x HPos	7	7.1	1.0		
VPos	1	1.6	1.6	0.18	0.688
S x VPos	7	62.9	9.0		
Pack x HPos	1	5.6	5.6	1.06	0.336
S x Pack x HPos	7	36.6	5.2		
Pack x VPos	1	0.6	0.6	0.33	0.588
S x Pack x VPos	7	12.0	1.7		
HPos x VPos	1	0.2	0.2	0.19	0.673
S x HPos x VPos	7	7.3	1.0		
Total	63	924.8			

* $p < 0.05$

Table 11. Differential static trunk angles .

	Internal frame				External frame			
	Close		Distanced		Close		Distanced	
Subject	Low	High	Low	High	Low	High	Low	High
1	8.70	5.95	4.98	8.03	9.36	10.27	1.28	3.17
2	6.11	11.01	9.35	6.48	6.35	6.70	6.67	5.56
3	9.77	7.21	6.38	3.46	4.54	7.58	6.44	3.56
4	2.73	9.87	7.33	5.75	6.41	5.47	6.70	5.16
5	9.00	7.09	6.93	6.31	3.56	2.60	5.05	7.03
6	6.24	5.74	3.99	3.43	0.49	2.12	3.54	2.90
7	6.14	3.52	6.15	5.25	4.06	2.20	3.33	6.43
8	4.56	0.98	4.52	3.90	4.12	3.37	0.89	3.55

Table 12. ANOVA of differential static trunk angles.

Factors	*df*	*SS*	*MS*	*F*	*p*
Within-subjects					
S	7	118.0	16.9		
Between-subjects					
Blocks (Pack x HPos x VPos)	1	35.5	35.5	23.68	0.002*
Blocks x S (S x Pack x HPos x VPos)	7	10.5	1.5		
Pack	1	1.1	1.1	0.39	0.558
S x Pack	7	19.9	2.8		
HPos	1	9.0	9.0	1.90	0.210
S x HPos	7	32.9	4.7		
VPos	1	0.0	0.0	0.00	0.976
S x VPos	7	17.2	2.5		
Pack x HPos	1	0.3	0.3	0.04	0.842
S x Pack x HPos	7	49.0	7.0		
Pack x VPos	1	3.0	3.0	1.01	0.347
S x Pack x VPos	7	20.4	2.9		
HPos x VPos	1	0.2	0.2	0.02	0.885
S x HPos x VPos	7	45.6	6.5		
Total	63	362.4			

* $p < 0.05$

Table 13. Differential dynamic trunk.

	Internal frame				External frame			
	Close		Distanced		Close		Distanced	
Subject	Low	High	Low	High	Low	High	Low	High
1	10.12	7.12	9.20	8.36	10.21	12.78	12.34	9.44
2	8.06	8.37	9.00	8.83	7.25	7.22	10.83	8.18
3	11.97	12.04	8.54	6.15	7.57	10.71	7.91	9.47
4	21.96	8.77	9.09	1.64	7.24	3.92	7.38	6.48
5	10.64	7.57	9.36	7.48	8.74	7.33	7.98	10.18
6	4.47	7.21	5.35	5.09	1.12	4.19	3.34	4.66
7	6.01	5.19	3.38	6.11	5.06	4.87	2.60	5.30
8	3.98	4.30	4.31	3.61	6.06	3.76	2.09	3.32

Table 14. ANOVA of differential dynamic trunk angles.

Factors	*df*	*SS*	*MS*	*F*	*p*
Within-subjects					
S	7	327.7	46.8		
Between-subjects					
Blocks (Pack x HPos x VPos)	1	28.5	28.5	7.91	0.03*
Blocks x S (S x Pack x HPos x VPos)	7	25.2	3.6		
Pack	1	3.2	3.2	1.56	0.25
S x Pack	7	14.3	2.0		
HPos	1	2.2	2.2	0.16	0.70
S x HPos	7	91.1	13.0		
VPos	1	25.7	25.7	5.51	0.05*
S x VPos	7	32.6	4.7		
Pack x HPos	1	20.0	20.0	2.31	0.17
S x Pack x HPos	7	60.3	8.6		
Pack x VPos	1	15.7	15.7	3.50	0.10
S x Pack x VPos	7	31.4	4.5		
HPos x VPos	1	0.7	0.7	0.20	0.67
S x HPos x VPos	7	23.9	3.4		
Total	63	702.5			

* $p \leq 0.05$

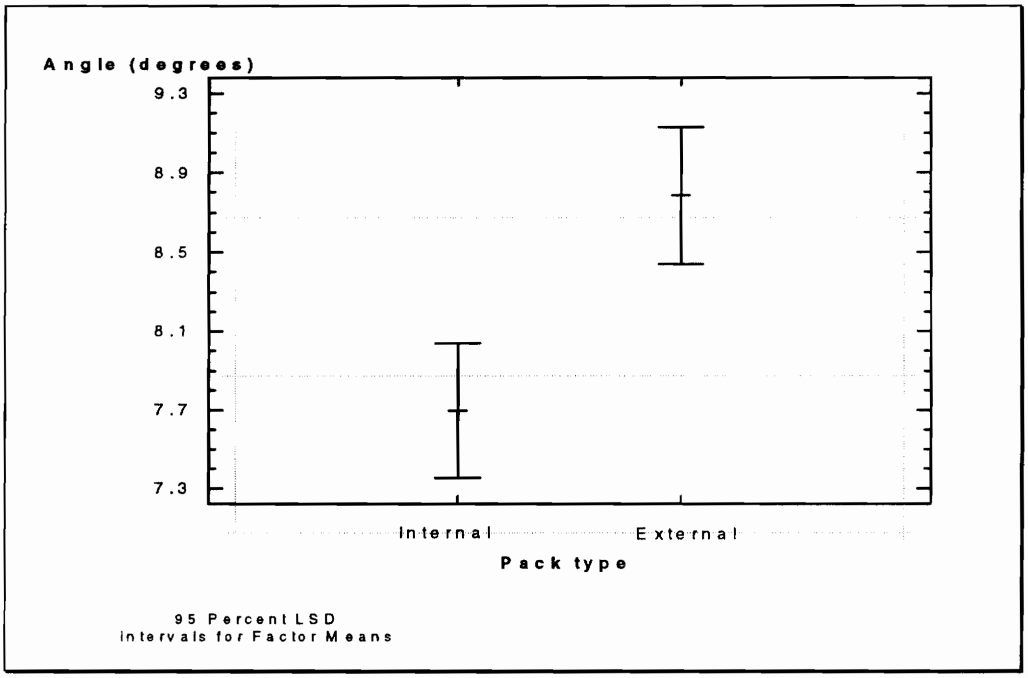

Figure 20. The effect of pack type on static trunk angles.

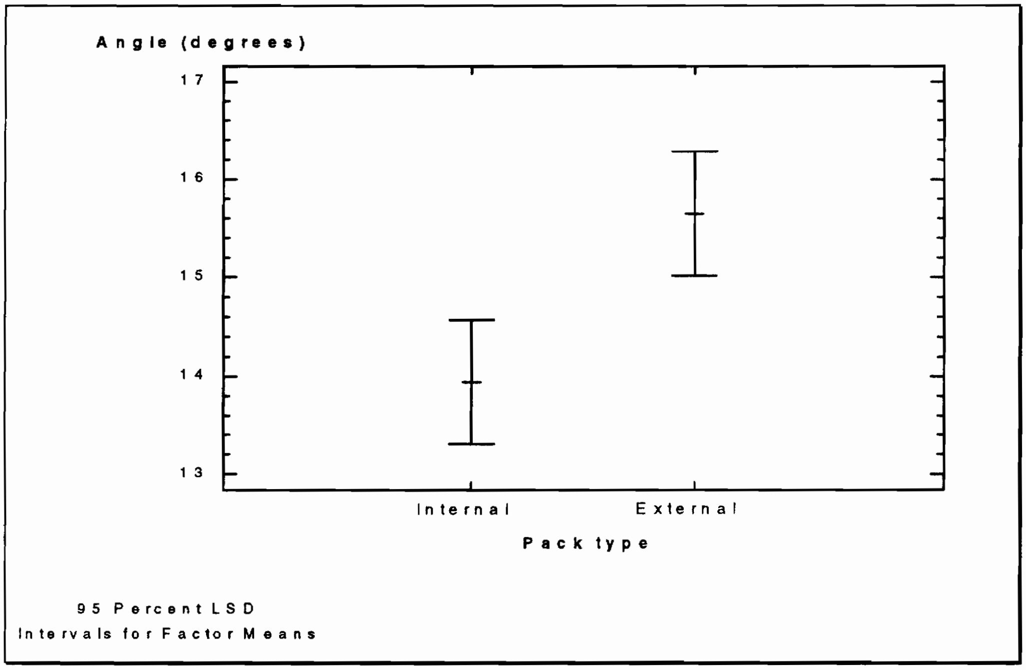

Figure 21. The effect of pack type on dynamic trunk angles.

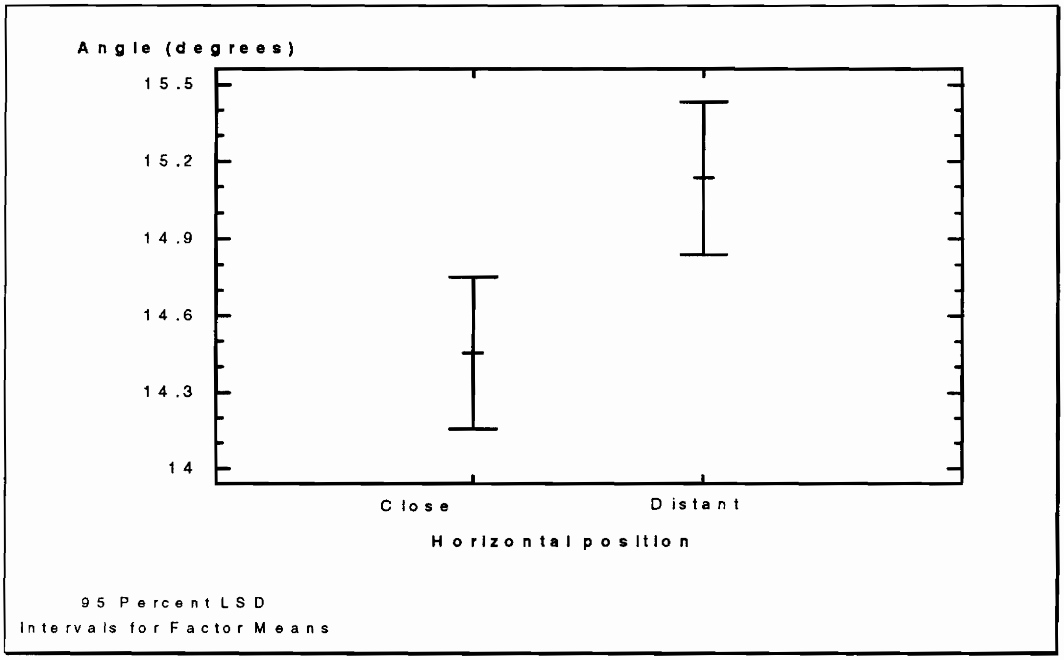

Figure 22. The effect of Horizontal load position on dynamic trunk angles.

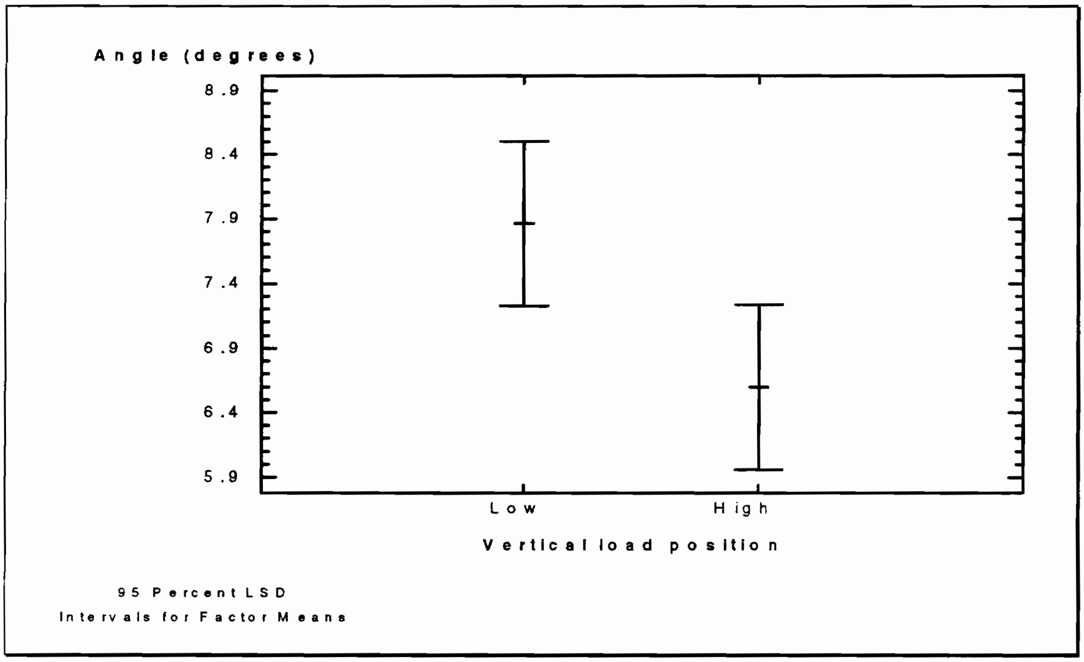

Figure 23. The effect of Vertical load position on differential dynamic trunk angles.

4.4 Cadence

Cadence was measured both during the reference condition, i.e. while walking on the treadmill with the unloaded backpack, and again once the final load had been achieved. Although there was no significant difference among the test conditions, the average cadence was found to be significantly lower ($p < 0.005$) when walking with the MAL than when walking without any load (Figure 24). This result was somewhat surprising, given findings reported by Martin and Nelson (1986). Further experimentation was carried out to verify the consistency of the treadmill belt speed under various conditions, and determine if a reduction in treadmill speed could account for this result.

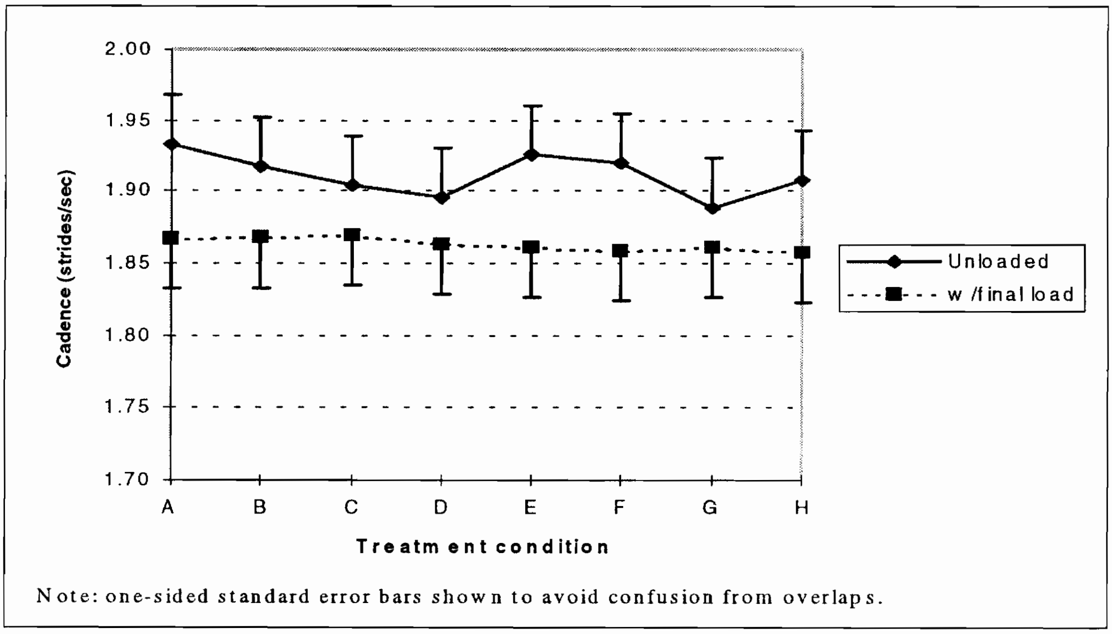

Figure 24. Average cadence and standard error as a function of load condition.

For the purposes of the post-test, a strip of adhesive tape was placed on the treadmill belt as a marker, so that the number of rotations per unit of time of the belt could be easily observed and measured. The treadmill speed was set at 4.7 km/hr (2.8 mph) and the time it took the tape to complete 10 cycles was recorded. This procedure was repeated five times for each of the three conditions, namely: the no-load belt speed (i.e. the speed without a test subject), the belt speed as a 77 kg test subject walked, and the belt speed as the test subject walked with a 13.6 kg (35 lb) load, including the external-frame backpack. The subject's weight and the size of the load were representative of the average of the male subjects' weights and of the maximum acceptable load they carried. The results, shown in Table 15, indicate that the belt speed decreased somewhat from the no-load speed as the subject walked on the treadmill. However, the addition of a 13.6 kg load did not have any appreciable effect.

Table 15. The effect of walking with or without load on treadmill speed.

	Test condition		
	No load	Subject	Subject + 13.6 kg
Treadmill belt speed (km/hr)	4.70	4.49	4.50
Standard deviation (km/hr)	0.01	0.01	0.01

An analysis of variance (Table 16) did not reveal any significant effect of the experimental conditions on Cadence.

Table 16. ANOVA of cadence.

Factors	*df*	*SS*	*MS*	*F*	*p*
Between-subjects					
S	7	0.540275	0.077182		
Within-subjects					
Blocks(Pack x HPos x VPos)	1	0.000900	0.000900	0.335	0.581
Blocks x S (S x Pack x HPos x	7	0.018800	0.002686		
Pack	1	0.000025	0.000025	0.061	0.812
S x Pack	7	0.002875	0.000411		
HPos	1	0.000056	0.000056	0.144	0.716
S x HPos	7	0.002744	0.000392		
VPos	1	0.000006	0.000006	0.018	0.896
S x VPos	7	0.002394	0.000342		
Pack x HPos	1	0.000006	0.000006	0.056	0.820
S x Pack x HPos	7	0.000794	0.000113		
Pack x VPos	1	0.000006	0.000006	0.014	0.908
S x Pack x VPos	7	0.003094	0.000442		
HPos x VPos	1	0.000100	0.000100	0.467	0.517
S x HPos x VPos	7	0.001500	0.000214		
Total	63	0.573575			

4.5 Comfort

Overall ratings of comfort were collected at the end of each 15 minute walk, followed by the identification of the body parts exhibiting the most discomfort. The comfort ratings, which were based on a 7 point scale going from "extremely comfortable" (1) to "extremely uncomfortable" (7), are given in Table 17 for each subject and condition. These data were analyzed using a Friedman Two-Way Analysis of Variance by Ranks test, to find out which, if any, of the conditions were considered any different from a comfort perspective. The results of this analysis did not support the notion that any of the conditions were significantly more/less comfortable than others (p = 0.103, adjusted for ties). However, the difference between test conditions may become significant with the use of a larger sample size.

Since comfort was thought to be related to the type of backpack, the data were recast as a function of Pack type and analyzed using the same statistical tool. The results showed a significant difference (p = 0.008) between Pack types, with Pack 2 (external-frame) appearing almost unanimously more comfortable to the subjects in this study.

Table 17. Overall ratings of comfort.

	Internal frame				External frame			
	Close		Distanced		Close		Distanced	
Subject	Low	Low	High	High	Low	Low	High	High
1	3.5	4	4	5	2	3	3	3
2	2	1.5	1	3	1	3	2	1
3	3	1.5	2.75	1.75	2.25	4.5	2.5	2
4	3	3.5	3	3.5	4	1.5	2	2
5	2	3	2.5	3	2	3	2	3
6	5	3.5	4.5	4	2.75	3.5	3	2
7	3	2.5	2.5	2	2.5	3	3	2.5
8	3.5	3	3	5	2	2.5	2	2.5

The body part discomfort results were treated in much the same way as by Corlett and Bishop (1976), making use of a special property of this method. As explained by the authors of this method, the number of different groups of body parts identified represents the number of intensity levels of pain experienced, and permits an increased level of pain to be recognized in the scoring. As the number of groups of body parts increases, so does the rating scale. For instance, with only one group of body parts identified, the scale would comprise two levels, one for the parts identified and one for those not identified. If more than one pain intensity level is identified, the scale increases its levels to match.

Four distinct body areas emerged as exhibiting some discomfort during the study: the neck (area 1), the shoulders (area 2), the back (areas 5 and 6) and the lower back (areas 7 and 8). Generally, the body parts identified during the ascending and descending load portions of the test were the same. When this was not the case, the ratings obtained in the second portion of the test condition (the descending series) were noted as representative of that test condition, since the subjects had worn the backpack for a longer period of time and were therefore in a better position to make a judgment. The discomfort scores were added across conditions (i.e. for all subjects) and are shown plotted in Figure 25.

A Friedman Two-Way Analysis of Variance by Ranks test was performed, as before, to determine if any of the test conditions were taxing particular parts of the body. This analysis indicated a significant effect on back discomfort among the conditions ($p = 0.025$, adjusted for ties), with condition G (internal-frame pack with Close and High load placement) exhibiting the largest discomfort. The test conditions did not have a significant effect on the shoulder discomfort ratings: $p = 0.062$, adjusted for ties. However, a larger sample size would likely show a significant difference. Discomfort ratings of the neck (p =

0.686, adjusted for ties) or the lower back (p = 0.684, adjusted for ties) showed no significant pattern among the test conditions.

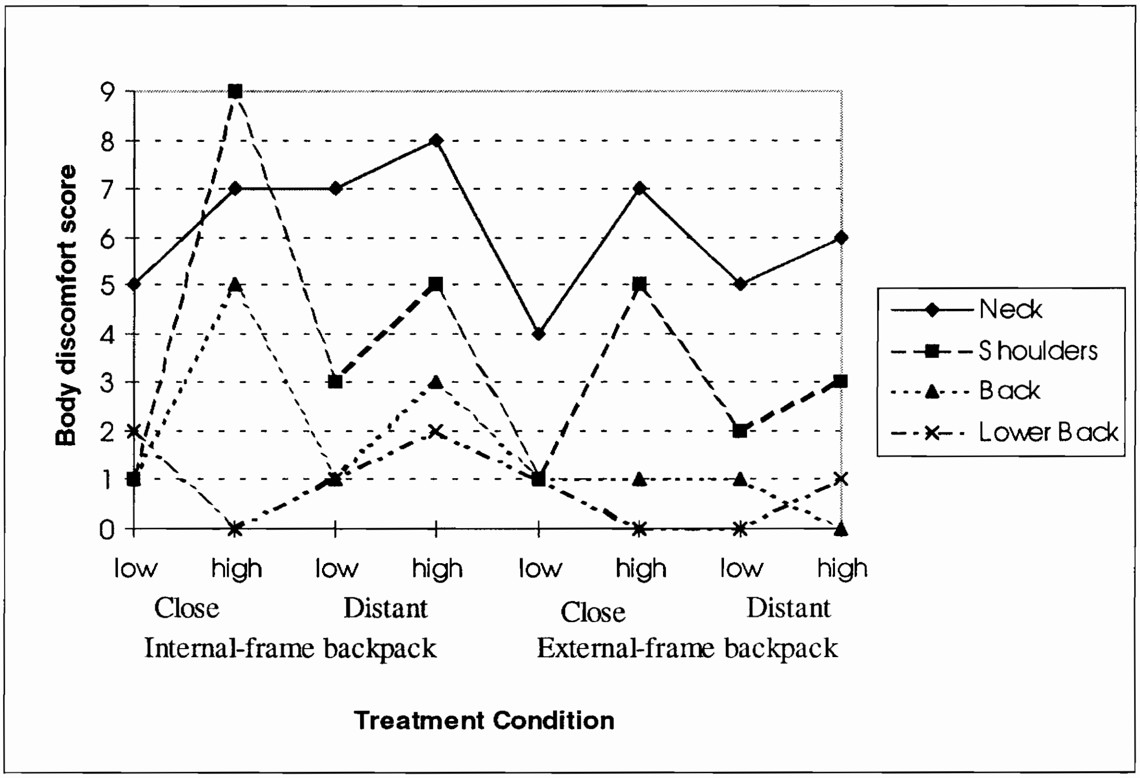

Figure 25. Body discomfort scores as a function of treatment condition.

As in the case of the overall discomfort ratings, the body part discomfort ratings were recast per Pack type to identify any pattern between the packs under study. The Friedman test found no significant difference between Pack types relative to body part discomfort, yielding p-values adjusted for ties of 0.059 for the Back, 0.096 for the Neck, 0.109 for the shoulders and 0.414 for the Lower Back area. Table 18 summarizes the data analysis results.

Table 18. Summary of Friedman 2-way ANOVA by ranks.

RESPONSE	**VARIABLE**	**p**	**p (adj. for ties)**
Overall discomfort ratings	Treatments	0.133	0.103
	Pack type	0.008	0.002*
	HPos	0.216	0.162
	VPos	0.596	0.549
Body part discomfort			
Neck	Treatments	0.935	0.686
Shoulders	"	0.254	0.062
Back	"	0.675	0.025*
Low back	"	0.993	0.684
Neck	Pack type	0.377	0.096
Shoulders	"	0.289	0.109
Back	"	0.377	0.059
Low back	"	0.724	0.414

* $p < 0.05$

5. DISCUSSION

5.1 Effect of load position on Maximum Acceptable Load (MAL)

One of the main objectives of this study was to investigate the differences in MAL between internal- and external-frame backpacks with respect to proximity of the load to the body, or horizontal load position (HPos). The basic premise was that loads carried closer to the body are easier to transport (Parkes, 1869). This is quite obvious when one looks at large differences, but the purpose of this study was to investigate a case where a relatively small difference exists. The main question in this study was: is a 4 cm difference in horizontal load position (difference between the internal- and external-frame backpacks in this study) enough to induce a noticeable increase in physical strain by people, or is it below the detection threshold?

The analysis of variance of the results gives mixed signals concerning this hypothesis. On the one hand, the main effect of Horizontal Position was not significant ($p = 0.088$), but the interaction of Horizontal Position with Pack type was ($p = 0.019$). Figure 18 clearly shows that horizontal distance had an effect on the internal-frame backpack, but not on the external-frame backpack. This indicates that something peculiar to the internal-frame backpack was causing the subjects to select smaller loads. As mentioned earlier, the internal-frame backpack used in this study suffered from a lack of rigidity which caused it to deform when loaded. It was also considered less comfortable than the external-frame backpack by most subjects. Both of these reasons could have played a role in the subjective perception of load acceptability and could certainly have contributed to the significance of the interaction. When these factors are removed, as in the case of the external-frame backpack, there appears to be no significant difference between the “close” and “distant” levels of the Horizontal Position variable. In fact, mean loads were identical. Hence, if a 4 cm difference was detectable by individuals, one would expect to observe its effect under both types of packs. Since this was not the case, it must be concluded this difference is not detectable unless extenuating circumstances exist, such as discomfort or lack of rigidity of the backpack.

5.2 Effect of load position on trunk angle and gait

A biomechanical analysis performed earlier on backpack load carrying capability revealed that a person's posture would have to change to counteract the addition of a moment. Thus, increasing the moment by moving the load away from the body should result in an adjustment in posture, or an increase in trunk angle. It was argued that a change in gait would accompany this adjustment, causing even more strain on the individual than a similar load placed closer. By using the psychophysical method of adjustment, it was expected that either a reduction in MAL would follow, or there would be an observable difference in trunk angle and/or gait as a result of varying the horizontal load position.

5.2.1 Trunk angles

Since the MAL was significantly smaller in the internal-frame backpack than in the external-frame backpack (p = 0.046), an observable difference in trunk angle would be expected. This is exactly what the ANOVA of absolute trunk angles reveals (Table 8), namely, that the subjects were standing more erect with the internal-frame backpack than with the external-frame backpack (p = 0.007). The same effect was observed dynamically, when subjects were walking with the MAL. The dynamic trunk angles were also significantly smaller with the internal-frame backpack (p = 0.015).

The first set of results (Tables 7 through 10) were related in terms of absolute trunk angles, i.e. without regard to the angle of the markers before the load was applied to the backpack. The second set of results (Tables 11 through 14) considered differential trunk angles, i.e. the effect of the added weight on trunk posture. Oddly enough, the two sets of analyses did not agree in terms determining the significance of effects. The subtraction of the initial trunk angle from the final one appeared to confound the effects by reducing the magnitude of the trunk angle and increasing the variability in the results. In both the static and dynamic differential angle ANOVAs, there was an apparent effect of Blocks on the outcome of the results (Tables 12 and 14). Since the blocking variable was the days on which the two parts of the trials were conducted, i.e. Day1 and Day2 (these were counterbalanced), there is no clear indication as to why this might have happened. In view of this effect, the results of the differential trunk angle ANOVAs, including the significance of Vertical position on the dynamic angles (Table 14), must be interpreted with caution. Further investigation would be required to determine the cause of this discrepancy.

5.2.2 Gait

Martin and Nelson (1986) found a tendency for stride rate to increase as the load was increased. This was not the case in this study, quite the contrary. As reported earlier, there was a significant decrease in stride rate ($p = 0.005$). This discrepancy may be a result of the difference in the methodology of the two studies. Martin and Nelson's subjects performed overground walking as opposed to treadmill walking. Controlling the walking speed (stride length and rate) of subjects is much more difficult under those conditions than with a treadmill. Also, the walking speed used was considerably higher than the one used in this study: 6.4 km/hr versus 4.7 km/hr. Accordingly, the subjects were walking closer to their maximum stride length and rate than they would be walking at 4.7 km/hr. At a speed of 4.7 km/hr, there is perhaps more room for adjustment between either the stride rate or the stride length to maintain a constant speed (stride length x stride rate = walking speed).

A possible explanation for the reduction in stride rate observed in this study may be that the inertial effect of the load acts to slow the weight transfer from one leg to another, much like the effect of increasing the mass of a pendulum slows its natural frequency. Given that the treadmill speed is constant, the reduction in stride rate must be accompanied by an increase in stride length. It may be easier for subjects to increase stride length than to alter the natural frequency of walking with the load. Thus, this effect may in fact be a strategy that reduces the total work output.

5.2.3 The psychophysical approach

The results of posture and gait analysis may indicate that since subjects were asked to find an acceptable load regardless of treatment condition, they selected one that did not induce an excessive amount of deviation from the natural posture. If this was the case, then a significant difference in trunk angle or cadence would not be expected. Thus, it could be partly because of the psychophysical method used that subjects adjusted the load until an acceptable posture and gait were obtained. Part of the psychophysical judgment may include making sure that one can walk fairly comfortably. In that light, a significant difference between the treatment conditions may not be a reasonable expectation.

5.3 Effect of Comfort on Maximum Acceptable Load (MAL)

One of the objectives of this study was to investigate the contribution of comfort in the psychophysical assessment of backpack load carrying. It was hypothesized that comfort may be a limiting factor in the amount of load a person feels capable of carrying over a time period, and that a comfortable backpack would be more conducive to carrying larger loads than a less comfortable one. This hypothesis was borne out by the experimental results: significantly higher loads were indeed selected for the backpack subjects considered more comfortable. Although this does not prove causation, it does appear to lend support to the hypothesis, or at least does not contradict it.

The average load carried in the external-frame backpack was 6% larger than in the internal-frame backpack. It would be reasonable to expect a heavier load, which would presumably cause higher stress on the body, to feel less comfortable than a lighter load. In other words, higher discomfort ratings would be expected as the load increases. This was not the case in this study. Although the subjects were carrying 6% more load in the external-frame backpack, they still felt more comfortable with that than with the smaller load in the internal-frame backpack.

5.4 General comments

The psychophysical method used in this study worked quite well. The subjects learned very quickly how to proceed, and were comfortable with the adjustment process within the very first cycle (comprising the ascending and descending load series). Only a few tests had to be repeated due to more than 15% difference in the ascending and descending series MALs, and those normally occurred on the first series.

The subjects were generally quicker to remove weight than to add it. The consistency of the results was found to depend on reaching a load that was slightly too large, and backing off from there.

Most, if not all, of the subjects were quick to comment on the comfort of the external-frame backpack once they had worn both. The consensus was that the contact area of the internal-frame backpack did not allow evaporation of perspiration, and that the bumps created by the channels designed to help air circulation felt uncomfortable. The open air feeling of the external-frame backpack probably had a positive effect on the perception of comfort when comparing both packs.

6. CONCLUSIONS

The load positions examined in this study did not appear to have an appreciable effect on the psychophysically-determined maximum acceptable load, except for the internal-frame backpack, which suffered from rigidity problems. The results of this study indicate that it is unlikely that significantly more load would be carried in an internal-frame backpack compared to an external-frame pack on the basis of the 4 cm difference in load center of gravity.

The maximum acceptable load that subjects carried was greater for the external-frame backpack than it was for the internal-frame backpack.

Subjects were more erect when carrying their maximum acceptable load with the internal-frame backpack as compared with the external-frame backpack. This was attributed, in part, to the fact that a lighter load was carried in the internal-frame backpack, on average. The Horizontal load position appeared to affect the dynamic trunk angle, where loads placed closer to the back induced less of an angle than the more distant placement.

Although there was no significant difference between the test conditions, a decrease in cadence between the unloaded and loaded conditions was observed. This may have been a manifestation of the pendulum effect whereby increasing the load decreases the natural frequency. It was postulated that it may have been a strategy used by the subjects to minimize the work output.

There was a significant difference in comfort between the two Pack types, mostly due to discomfort at the shoulders and back. The external-frame backpack was found to be more comfortable, even though larger loads (6% larger) were carried in it. The comfort properties of the backpack appear to be an important factor in subjects' determination of a load they believe they can carry for an eight hour trek. The test subjects carried a larger load (6% larger) in the backpack they considered to be the most comfortable.

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APPENDIX A

Physical Fitness Questionnaire.

Name:________________________________ SSN:______________

Address:____

Telephone number:_______________ Date of Birth (day/month/year):_____________

How would you describe your current physical condition (circle one):

Poor Fair Good Excellent

Please answer the following questions by a yes or a no. If you answer yes, please feel free to elaborate.

Have you had back pain during the last year?	Yes	No
Have you ever had any back pain?	Yes	No
Have you had any joint dislocation, broken bones or other physical injury in the last year?	Yes	No
Are you presently taking any medication or drugs?	Yes	No
Do you currently have any physical impairment worth noting?	Yes	No

____

Signature and date

APPENDIX B

Test Instructions Given To Participants.

(Adapted from Jiang, Smith and Ayoub (1986))

The objective of this study is to investigate the load carrying ability using two different types of backpacks. The activities of the test will consist in walking with the loaded backpacks on a treadmill, at a speed of 4.7 km/h (2.8 mph) for 20 minutes at a time without straining yourself or without becoming unusually tired, weakened, overheated or out of breath..

This is <u>not</u> a test to determine your maximum weight carrying capacity; rather, it is a study to find reasonable quantities that you think you would feel comfortable carrying over an 8 hour day.

We want you to imagine that you are embarking on a week long trek on the Appalachian trail, and that you need to carry as much load as reasonable, knowing that the more stuff you bring, the more comfortable your trek will be.

The backpack load will be adjusted as per your instructions. If you feel that you can carry more load, just tell the experimenter to add "a lot", "much", "some" or "a little" weight to the backpack, depending on how much adjustment you require. If you feel you are carrying too much, tell the experimenter to remove "a lot", "much", "some" or "a little" more weight. You decide what is "just right" to carry for an entire day.

Don't be afraid to make adjustments. That's the only way you can find out what feels like a comfortable load. You have to make enough adjustments so that you get a good feeling for what is too heavy and what is too light. You can never make too many adjustments, but you can make too few.

Remember, this is not a contest. Not everyone is expected to carry the same amount of weight. We want your judgment on how much you can carry without becoming unusually tired.

Remember to tell the experimenter how much weight to add or remove, so that the final backpack load represents the maximum weight you would be willing to carry at this pace, for an entire day.

APPENDIX C

Informed Consent Form

Title of project: Psychophysical Assessment of Load-carrying in Internal and External-frame Backpacks

Principal Investigator: Pierre Meunier

I. PURPOSE OF PROJECT

You are invited to participate in a study about backpacks. This study involves experimentation for the purpose of determining the effects of biomechanical differences between loads carried in an internal-frame backpack and in an external-frame backpack.

II. PROCEDURES

You will be asked to walk on a treadmill with a loaded backpack at a comfortable pace (4.7 km/h or 2.8 mph) for 20 minutes at a time. During that 20 minutes you will be asked to increase or decrease the amount of load until you feel it is "just right". There will be eight backpack conditions, and each condition will be repeated once, for a total of sixteen 20 minute walks. You will be asked to participate in two sessions of approximately 3½ hours each. You will not compete with other subjects.

The possible risks are that you may not be able to maintain the treadmill pace on occasion. Your judgment will provide the first safeguard against using too large a load. Furthermore, the treadmill has two handrails for support and stabilization before, during and after the walking period. As a third safeguard, the treadmill has a safety device (a "power key") that will immediately cut off power if you fall behind in the pace. No other psychological, sociological or physical risks are expected from participation in this project, since the object is to arrive at a "reasonable" load. The experimental sessions should not cause undue fatigue or stress: it should be roughly equivalent to playing a round of golf, carrying a set of clubs.

III. BENEFITS

Your participation in this study will enable us to use a different approach for the comparison of two types of backpacks. This project may also shed some light on the significance of the biomechanical differences between internal and external-frame backpacks, and the benefits of two different Pack systems.

No guarantee of benefits has been made to encourage you to participate.

You may receive a summary of the findings of this project by bringing a self-addressed envelope in the second test session.

IV. EXTENT OF ANONYMITY AND CONFIDENTIALITY

A code number will be assigned to each subject to maintain anonymity. Any information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research.

The experiment will be taped. These tapes will only be reviewed by Pierre Meunier, and will be erased within 4 weeks of project completion.

V. COMPENSATION

For participation in this project, you will receive $5.00 for each hour completed, for a total of $35.

VI. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time without penalty. If you chose to withdraw, you will be compensated for the portion of time of the study.

There may be circumstances under which the investigator may determine that you should not continue. If this occurs, you will be compensated for the portion of the project completed

VII. APPROVAL OF RESEARCH

This research project has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University, by the Department of Industrial and Systems Engineering. Additional questions concerning your rights should be addressed to the Chairman of the Institutional Review Board, 301 Burruss Hall (231-9359).

VIII. SUBJECT'S RESPONSIBILITIES

I know of no reason why I should not participate in this study. I understand that I have the following responsibilities:

i) to complete the physical fitness questionnaire
ii) to refrain from strenuous activity on the day of the test, until test is completed.

Signature and date: ______________________________

IX. SUBJECT'S PERMISSION (tear off at dashed line to give to subject)

I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Should I have any question about this research or its conduct, I will contact::

Pierre Meunier, Investigator	231-6053 or 951-9375 (home)
Dr Kroemer, Faculty Advisor	231-5677
Chair, Institutional Review Board	231-9359

APPENDIX D

Summary of procedure supplied during testing (poster)

1) Stand between lines, hands on belt:
   use a natural position, center your weight in the middle of your stance.
   (Your posture will be recorded for 10 seconds, so stand still.)

2) Start the treadmill:
   - with feet on the sides, increase speed to 1.5 mph.
   - get on moving surface carefully and increase to 2.8 mph. Hold the ramp if necessary.

3) As you walk ask yourself:
   - Is this load "just right" for a day trek?
   - How much should I add/subtract?
     i) a Large amount
     ii) a Medium amount
     iii) a Small amount

REMEMBER TO MONITOR YOUR BODY:

This is not a test to determine your maximum weight carrying capacity;

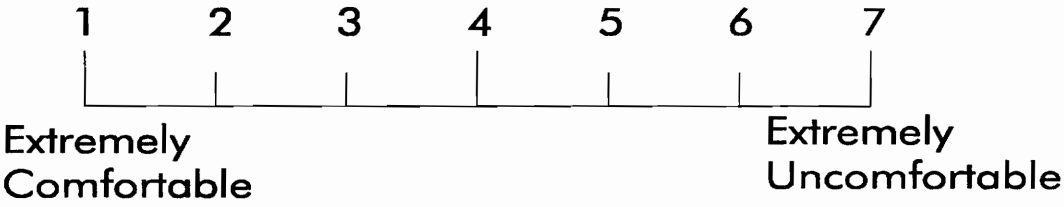
We want you to find reasonable quantities that you can carry on a day trek.

The load carried should <u>not</u> cause you to strain yourself or become unusually tired, weakened, overheated or out of breath.

4) When the test is over, press the Stop button on the treadmill.

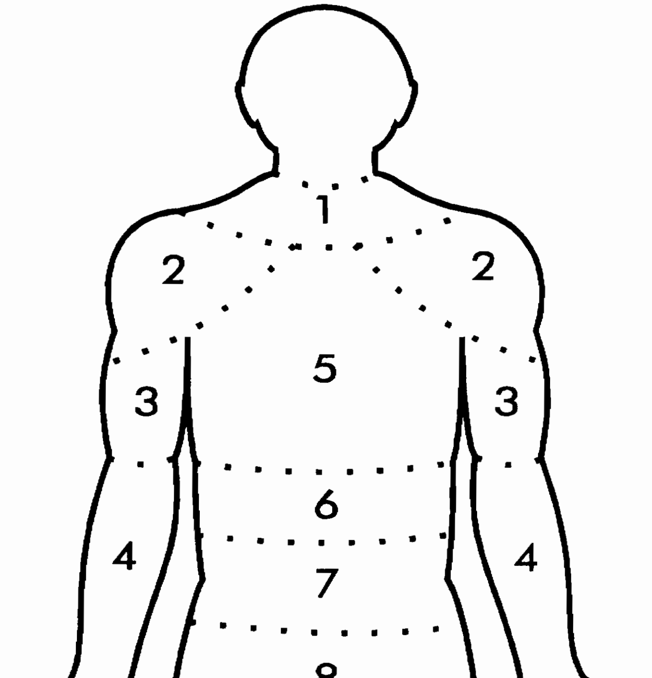
5) Stand still, arms in front (posture recording)

6) How would you rate your overall comfort?



7) Which area(s) of your body is the most uncomfortable? (see diagram)
Which is the next most uncomfortable?

Regions of most discomfort



VITA

Pierre Meunier was born on February 23, 1960, in Montreal, Quebec, Canada. He received his bachelor degree in Mechanical Engineering at McGill University in December 1981. He worked at the Defence Research Establishment Ottawa until July 1993, when he moved to Blacksburg, Virginia to receive post-graduate training in Human Factors Engineering at Virginia Polytechnic Institute and State University. He will be working in the Human Factors Division of the Defence and Civil Institute of Environmental Medicine, in Toronto, Ontario, Canada, after completion of his master's degree.

Pierre Meunier

Pierre Meunier