EFFECTS OF INCREMENTED LOADS OVER PREFERRED VALUES ON PSYCHOPHYSICAL AND SELECTED GAIT KINEMATIC FACTORS

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ABSTRACT

This study investigated the effects of incremented loads greater than maximal acceptable loads on selected locomotor kinematic and psychophysical variables for four different hand-held load-carriage methods.

Ten male and ten female subjects, between the ages of 18 and 30, participated in four experimental sessions. Data collection involved obtaining selected anthropometric, strength, maximal load and preferred load, gait kinematic, and psychophysical values. The anthropometric, strength and load capacity variables enabled absolute and morphology-normalised sex-based comparisons to be made. The kinematic and psychophysical parameters were used to quantify any changes from two sets of baseline values,"unloaded" and "maximal acceptable load" values, when loads were increased and carrying methods changed.

Statistical analysis revealed that males were taller, heavier and stronger than females ($p<0.05$). Males chose significantly greater maximal acceptable loads and absolute maximal loads than females when expressed in either absolute or relative terms. Preferred walking speeds were not significantly different for unloaded or loaded conditions, although males walked significantly faster in absolute terms (but not in relative terms) than females. Different load carrying methods and incremented loads brought about significant changes to several of the kinematic parameters investigated. Finally, ratings of perceived exertion, as well as the number of exertion sites, were seen to increase significantly as load increased. These values were not, however, significantly affected by differences in load-carriage method.

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CHAPTER 1

INTRODUCTION

Load carriage lies on a continuum ranging from very light to maximal loads (Broer and Zernicke, 1979). Along this continuum normative values have been established that are structurally, physiologically and psychophysically acceptable (Snook et al.,1970; Snook and Ciriello, 1974; Evans et al.,1980; Mital and Manivasagan,1983; Snook,1985). Biomechanical models which describe human lifting tasks, for example the "NIOSH" model (NIOSH,1981) , are based largely on analysis of the failure of supportive structures under mechanical stress. Using this type of model it is suggested that "maximal permissible" limits (MPL) should not be exceeded as structural failure may occur beyond these values. The concept of "maximal acceptable loads" (MAL), obtained by psychophysical perception for various work rates, has great utility (Snook, 1978 and 1985; Mital and Manavasagan, 1983). Psychophysical limits for various load carriage tasks comprise individual human perceptions which are probably formulated through the experience of impaired movement, excessive physical effort, pain, injury, or the decision that the task may cause injury or fatigue. Clearly "experience" is the operative word in this scenario.

The stress to bodily structures imposed by many of the tasks encountered in everyday situations often exceeds "maximal acceptable" values as outlined by the literature (Grandjean, 1980) and (if MAL criteria are validly based) may consequently expose the person carrying the load to injuries or risk of injuries typically associated with excessive loading. Thus there is a need to study human response to loads which exceed research derived MAL criteria, but which nevertheless lie within the physical and psychophysical perceptual capabilities of the individual. (Such loads are typical of everyday situations). Study in this field might reveal biomechanical patterns and psychophysical perceptions that are typically present when the body's reserve capacities for physical work are extended. Furthermore, the recognition of "transition responses" between acceptable and non-acceptable, as determined jointly by personal work perceptions as well as unstable gait patterns, may enable the prevention of possible injury.

Load carriage doubtless has ancient origins which probably stem from the transition to a fully upright and bipedal posture. As a gatherer and later a hunter-gatherer early man was frequently involved in carrying his offspring as well as the animals and edible plant materials used to supply the needs of the group. Today man is still involved in carrying loads and such activities may be seen in every facet of modern human existence (Oguro, 1982; Kinoshita, 1985; Legg, 1985). The economic importance of human load carriage is nowhere better illustrated than in developing countries where other means of load transport are limited and where there is dependance on human load carriage for economic development

(Kinoshita,1985).

Understanding the effects of load carriage on man requires knowledge of structural and functional human limits (Frankel and Nordin, 1980; Sperryn, 1983). Thus familiarity with the workings of the musculoskeletal system is essential for optimising human load carriage. Man's bipedal locomotion allows the arms to be used for tasks such as manipulation and communication while standing as well as walking (Charteris et al., 1976). However, unlike the quadrupedal locomotion of terrestrial animals, superencumbent trunk, arm and head weight has to be supported by the lower limbs and the linking structure of the spine alone. Closer examination of the structures of the lower spine reveals that this region is particularly prone to loading associated injuries (Frankel and Nordin, 1980; Sperryn, 1983). Man's upright posture has been an evolutionary development from postures which were less erect than the present form (Napier, 1967). In this evolutionary development the spine has had its supportive role increased while it has retained its great range of motion in a number of axes and planes. Flexibility of functioning is not acquired without a price; thus retaining the extensive movement capabilities of the spine has reduced the effectiveness of the spinal structures to support superencumbent weight. The greatest relative deficit of structural strength is particularly evident in the lumbosacral region, where biomechanical stresses are high owing to the nature of the spine's design (Frankel and Nordin, 1980; Sperryn, 1983).

The human body, similarly to a man-made machine, will continue to function properly provided it is used within its design limits and is properly maintained. Like any machine, however, aging and continuous use will progressively reduce the working capacity of the body and eventually working parts will break down. Biological structures do not have entirely suitable artificial replacements and therefore functional mobility is compromised if structures are damaged. Furthermore, nature does not design its structures to last indefinitely and although biological materials deteriorate with age, disease and improper use, correct training together with proper lifting methods may retard such processes and in some cases restore loss of function even into old age (Frankel and Nordin, 1980).

Having established that man is involved in carrying loads on a regular basis and that his body is the means through which this objective is achieved, it is necessary to become familiar with common methods of load carriage and to understand the motor patterns of bipedal load carriage (Pierrynowski et al., 1981; Kinoshita, 1985; Martin and Nelson, 1986; Charteris et al., under review). The kinematics of load carriage requires the consideration of three areas of investigation; the nature of the gait cycle, the mechanism of load support, and the interaction between bipedal locomotion and the mechanism of support. Compounding the difficulty of analysis is the fact that efficient gait involves the integration of head, trunk and arm movements in conjunction with those of the legs, where these parts of the body optimally assist and balance lower leg movement (Murray, 1966).

The size, shape and mass of the load play a decisive role in the manner in which normal gait patterns will change under load conditions (Martin and Nelson, 1986). Increasing incumberance owing to the nature of the load has been seen to result on the greatest changes from normal or optimal movement patterns (Martin and Nelson, 1986). There are numerous load carrying methods, however, all of which fall into one of two categories. The first category can be described as natural loading, where the load is coupled to the body without the use of assistive devices. The second category requires devices such as backpacks or yokes to improve the man-load couple and consequently improve efficiency of the designated task (Garg et al., 1980; Legg, 1985). However, under investigation in this study were various hand-held carrying methods which are universal and typical in everyday activities, both at home and in industry (Oguro, 1982).

The biomechanical, physiological and psychophysical responses of man to load-carriage tasks may be found in the investigation of musculoskeletal changes, physiological adaptations and psychophysical attitudes towards such work (Snook et al., 1970; Kinoshita, 1985; Martin and Nelson, 1986). Recently the prevalence of problems related to load carriage has been illustrated by numerous research reports concerning the incidence of Lower Back Pain Syndrome (LBPS) (Biering-Sorensen, 1985; Davis, 1985; Metzler, 1985; Nicholson, 1985).

The primary aetiology of LBPS stems from the mismatch between the functional capabilities of the lower spine and the tasks demanded of it, where decreasing tolerance to load conditions, owing to aging and adverse individual experiences, are responsible for the development of this condition. The cost of LBPS can be measured for example in the loss of manhours and medical expenses, as well as workmans compensation claims (David, 1985). Lower back pain syndrome has been described as the single greatest cause of work absenteeism and reduced physical capacity of the individual (Grandjean, 1980).

To do justice to the subject of load carriage a multidisciplinary approach which carefully integrates biomechanical, phsyiological and psychophysical methods is preferable as such an approach presents an holistic picture of human responses to load carriage. Biomechanical techniques are uselful to describe or quantify kinematic patterns and dynamic posture under unloaded, and load-carrying conditions. It is, however, man's psychophysical perceptions that finally determine the extent, the manner and rate at which loads are carried or work is done. Through psychophysical methods perceptions of exertion, maximally acceptable loads and maximal carry limits have been obtained. Normative load values and ratings obtained through psychophysical means have been used to set work intensities and load limits in industry today.

STATEMENT OF THE PROBLEM

The purpose of this study was to establish whether incremented loading (above maximally acceptable levels) had any effect on biomechanical and psychophysical measures taken when loads were carried using various arm-supported or hand-held methods. Furthermore, differences, if any, between males and females in morphological and strength parameters were invesigated, as these may have accounted for differences in load carrying ability.

Biomechanical measures of gait patterns under unloaded and loaded conditions and psychophysical ratings of perceived exertion for local and overall perceptions were used to assess male and female responses to the different carrying tasks. Any changes in the measures investigated may have been attributed to one or more of the three variables: namely sex, method of load carriage and the mass of the load.

According to Kinoshita (1985) and Martin and Nelson (1986), all three of these variables could be responsible for differences seen in the biomechanical and psychophysical measures taken.

RESEARCH HYPOTHESES

1. The imposition of different load-carrying methods at any comparable incremented load level is not responsible for significant differences in the dependent variables measured in the areas of locomotor kinematics and

psychophysics.

Mathematically stated:

H_0: $\mu_{uni} = \mu_{bi} = \mu_{flx} = \mu_{ext}$

H_A: $\mu_{uni} \neq \mu_{bi} \neq \mu_{flx} \neq \mu_{ext}$

(Where uni, bi, flx, ext. refer to four discrete load-carriage methods described on page 43)

2. The carrying of individually selected maximal acceptable loads (MAL) (and of further fixed increments in percent of MAL) is not responsible for significant differences in the dependent variables measured in the fields of locomotion kinematics and psychophysics.

Mathematically stated:

H_0: $\mu_P = \mu_{P25} = \mu_{P50} = \mu_{P75}$

H_A: $\mu_P \neq \mu_{P25} \neq \mu_{P50} \neq \mu_{P75}$

(Where P, P25, P50, P75 refer to load-increment levels described on page 48)

3. The load-preference capacities and morphology-normalised strength performances of males and females are equal with respect to the carrying methods studied.

Mathematically stated:

H_0: $\mu_{m(a,s)} = \mu_{f(a,s)}$

H_A: $\mu_{m(a,s)} \neq \mu_{f(a,s)}$

(Where m = males, f = females, a = anthropometry, s =

strength, see page 56).

DELIMITATIONS

Guidelines exist for the recognition of maximal acceptable loads (MAL) to be carried by various populations (Snook, 1978). The present study considered load increments in excess of MAL levels together with unloaded levels, and represents an interrelationship matrix contrasting loads in excess of MAL versus MAL and unloaded levels. The biomechanical factors examined comprised various kinematic parameters of gait. The psychophysical measures comprised ratings of "overall" and of "local" perceived exertion, as well as the identification and tally of local sites of exertion. Finally, a number of anthropometric, strength and carry-capacity measures were taken in order to describe the sample. Data from these sources were used to determine whether incremented mass, carry-methods and sexual dimorphism elicit different movement patterns, physical performances and psychophysical perceptions. The maximal acceptable loads chosen by the subjects of this study were compared to those in the literature.

The sample selected consisted of 10 male and 10 female subjects between the ages of 18 and 30. Subjects were students of Rhodes University who were able-bodied and healthy. For the purposes of this study subjects were grouped according to sex. The tasks asked of the subjects were of such a nature that no habituation was necessary. However, an explanation of what was expected by the researcher was given to each subject before data were collected. Subjects were not naive about the procedures of the study as all had been involved in either a test-retest reliability study involving 10 males, or a larger study involving 25 males and 25 females (Nottrodt and Manley, under review). The purpose of these studies was to test the reliability of maximal acceptable loading, as well as obtain baseline data on South African Caucasian adults.

The procedure involved the collection of anthropometric data before loads were carried. Biomechanical data were collected during load carriage, and psychophysical data were gathered upon completion of each trial.

LIMITATIONS

In this study a number of physical and psychological phenomena characteristic of load carriage were recorded. As a consequence it was necessary to understand the precision and appropriateness of the data collection methods. The technology for gait kinematics has become ever more sophisticated. However, for the purposes of this study only the more gross events of the gait cycle were required. The risk of this choice was that it might miss trends that could have been demonstrated if a more sensitive technology was used.

The nature of psychophysical perceptions is such that there is always a measure of uncertainty owing to the variability of human perceptual judgements. However, giving subjects a clear explanation of the working of rating scales and load task demands, and having selected subjects who had been previously exposed to such psychophysical tasks, ensured the achievement of meaningful results.

This study also referred to load carriage norms which provide guidelines for carrying tasks (Snook, 1978). These guidelines were established using foreign populations. Pilot work for the present study, however, revealed that data gathered by the researcher were not significantly different from those reported by the literature (Snook, 1978).

In this study anthropometric data were used to describe and categorise subjects. Although there is no one measure of strength that embraces overall capacity, grip-strength has been shown to be an acceptable indicator. Furthermore, tasks performed by the subjects of the present study depended heavily on the use of the hands to couple the load to the body. It was on the grounds of reliability and appropriateness that hand-grip strength was chosen for this study.

Finally, the small sample size of 10 males and 10 females was considered acceptable (but only marginally so), because pilot work done by the author on reliability and norms generation (Nottrodt and Manley, under review) tended to justify this contention.

CHAPTER 2

REVIEW OF THE LITERATURE

The manual transportation of loads, with or without assistive devices, may serve to define human load carriage. Load transportation is dependent upon upright bipedal locomotion to displace the load, and also on either an unassisted or assisted coupling of the load to the body. As with any working activity, the stress imposed by load carriage depends on the frequency, intensity, nature and duration of the task, and in everyday situations these variables are free to change.

Load carrying and the manual handling of material are basic activities in which man is involved on an everyday basis (Broer and Zernicke, 1979; Oguro, 1982). Kinoshita (1985) points out that for reasons of survival, migration, commerce, warfare and construction, men and women have for millenia carried infants, belongings, weapons, food supplies and building materials. Man's versatile working capacity has been exploited throughout history and is still indispensable in contributing to the functioning of many a developing economy (Kinoshita, 1985). Manual materials handling (MMH) is not only limited to developing nations where the absence of sophisticated labour-saving technologies are apparent, but remains indispensable in many work settings even in developed nations. In industry, as well as in domestic and community health care service, the versatility of hand-held load carriage styles is evident in the diverse tasks involving lifting, carrying and lowering of objects as well as people.

The prevalence of load carriage and especially the detrimental effects of the mis-handling of loads has become a highly contentious issue in developed countries today. Snook (1985) makes the point that strain-induced injuries associated with lifting and carrying should be categorised as follows: (1) Low-back pain; (2) low-back impairment; (3) low-back disability; and (4) low-back compensation. Briefly, low-back pain involves chronic or acute pain in the lumbosacral, gluteal and thigh regions, and is experienced by as much as 80% of the population in the USA. Low-back impairment describes the condition wherein performance in carrying out tasks is reduced, primarily because of the severity of the pain. Low-back disability is described as a state in which the worker is no longer able to perform the task, and is accomodated at the workplace by performing other duties. Low-back compensation occurs when monetary compensation is made to a worker deprived of the ability to earn wages from regular employment.

The cost of these work-related conditions is considerable and numerous authors have described this cost, which can be measured in lost man hours, medical expenses and workman's compensation claims (Biering-Sorensen, 1985; David, 1985; Metzler, 1985; Nicholson, 1985). A number of approaches have been made to tackle this epidemic problem, and answers have been sought in the analysis of both man and task, in the hope of determining which factors are the predominant precipitators of lower back incidents. Deeb et al. (1985) have suggested that the best lasting approach is to address the mismatch between man and load, and to redesign the task, as well as the container, to fit the man. Other approaches focus on man's physical, psychological and intellectual make-up in order to establish safe limits for working capacities. The physical limits and recommendations concerning MMH tasks have been expressed in physiological terms (Evans et al., 1980; Pierrynowski et al., 1981; Gordon et al., 1983), in biomechanical and structural terms (Frankel and Nordin, 1980; NIOSH, 1981; Sperryn, 1983), in psychophysical terms (Snook et al., 1970; Snook and Ciriello, 1974; Snook, 1978, Ciriello and Snook, 1983; Snook, 1985), and in the teaching of correct methods of lifting (Broer and Zernicke, 1979; Grandjean, 1980).

Recently there has been a shift towards approaching the study of man-in-motion in an holistic way, such as has been advocated by Charteris et al. (1976). Pierrynowski et al. (1981), Kinoshita (1985), Martin and Nelson (1986), and Jaing et al. (1986) have all recognised the importance of a multidisciplinary approach where physiological, biomechanical, psychophysical and epidemiological factors should be considered. Although much work has been done in regard the varied aspects of MMH, and optimal working limits have been established, these suggestions have not reduced the incidence of low-back pain to any significant extent, but have made a significant impact on the reduction of low-back disability and compensation (Snook, 1985). It has also been suggested that the imposed limits to MMH work may diminish the occurance of painful episodes on the job, while at the same time allow the worker to continue working for a longer time, and furthermore allow the worker to resume work sooner after being temporarily disabled. Although use of permissible load standards goes some way towards counteracting the problems associated with MMH, the success of such an approach is confounded by human variables such as spinal changes with aging, poor lifting techniques and high forces encountered when load slippage occurs or when a person becomes off-balanced.

SEX DIFFERENCES AND INDIVIDUAL VARIABILITY

In the past there has been the tendency to only consider responses of males to load carrying tasks (Martin and Nelson, 1986) and relatively little research has been done on females. Furthermore, work that has been done has concentrated on caucasian males while other racial groups, of characteristically different anthropometry, have tended to be neglected. Recently more has been done in correcting this imbalance and studies involving both sexes have been undertaken (Snook, 1978; Monod and Zerbib, 1985; Martin and Nelson, 1986). Both sexes of all nationalities are involved in some sort of load carriage on a daily basis (Kinoshita, 1985).

Oguro (1982) described hand-held load carriage as the most typical in everyday situations. To form a basic picture of the extent to which males and females differ in basic anthropometry, McArdle et al. (1986) considered the concept of a reference man and woman. Essentially they summarise the differences between the sexes by describing males as being taller and heavier, and as possessing greater muscle mass and less fat mass. The possible causes for this lean body mass disparity may be biological or behavioural in nature, as in general, males tend to be more active and do not require the same "essential fat" stores for healthy functioning. Individual anthropometric differences may vary considerably within and between sexes and these differences may be behaviourally, genetically or nutritionally based. Furthermore, females cannot be described as merely scaled-down versions of males, although they are similar, they are functionally different in respect of reproduction: skeletally, for instance, they differ marginally in the shape and size of some structures, in particular the pelvis and the width of the shoulder girdle (acromial width).

Differences in absolute and relative size between the sexes account for the larger portion of the difference in performance values attained by males in strength tasks and in preferred-load selections (Snook, 1978; Charness, 1985; Monod and Zerbib, 1985). In the choice of preferential loads, female values may also be marginally reduced by their lack of lifting and carrying experience. Muscle strength is, however, proportional to cross-sectional area, and for human muscle the force that can be generated is in the order of 3-4 $kg.cm^{2}$, regardless of sex (McArdle et al., 1986).

Thus, when MMH is considered, the worker (male or female) who possesses the greater amount of working muscle, usually the male (Monod and Zerbib, 1985), would be able to accomodate the load more easily. When loads are carried using the hands, upper-body musculature is particularly stressed.

FORCES IMPOSED ON THE SUPPORTIVE STRUCTURES

Coupling of loads to the body through the use of the hands implies that the mass becomes part of the total body weight (Broer and Zernicke, 1979). Even more crucial, however, is the fact that the load is indirectly imposed in the region of the shoulder and thereby becomes part of superencumbent weight and thus comprises a force that is transmitted down the majority of the spine's length. Hand-held loads require upper-body stabilisation in the form of static muscular contractions, and, depending on whether the loads are held frontally or laterally, additional activity of erector spine is required in order to compensate for the resulting trunk flexion (Broer and Zernicke, 1979). The compressive loads on the spine comprise forces generated to resist external movements and the natural compression imposed by gravity virtually downwards through the spine, and are seen to increase considerably when the upper-limbs are extended in front of the body (Andersson, 1985). Grandjean (1980) describes the vertebral column as having the shape of an elongated S. In this form the spine is able to absorb shock. Furthermore, owing to its load-bearing design, and aided by supporting musculature and interabdominal pressure, the spine can resist substantial loading. Healthy individual segments, in particular the end-plate or vertebral bodies of the lumbar region, can withstand forces of approximately 5000 to 8000N (Eie, 1966, as cited by Frankel and Nordin, 1980) and will usually fracture before the disc is damaged. Of particular interest to load carriage are the vertebral units of the lumbar spinal region, as these are predominantly responsible for weight bearing. The motion mechanics of structures of the lower spine and pelvis allow for forward flexion of the trunk, a movement required when objects are being lifted from low levels. As a consequence of this bending, tensile stress rises in the annulus fibrosus and the disc bulges on the concave side of the spinal curve and contracts on the converse side (Frankel and Nordin, 1980; Sperryn, 1983). Forward flexion furthermore increases the magnitude of the shear forces, as the spine is no longer in the favoured position of accomodating axial compression centrally on the nucleus pulposis. Instead, it is in an eccentrically stressed position in which forces are not distributed equally within the disc and are in directions at a tangent to the favoured resistance direction of the disc.

Research has yet to quantify the forces imposed on the various components in the motion segments (in vivo) and the way in which these structures are influenced by age, tissue degeneration, neuromuscular factors and fatigue (Andersson, 1985). However, it is clear that the spine's supportive function is maintained and possibly enhanced when the supporting musculature of both the back and abdominal regions is well conditioned (Frankel and Nordin, 1980). In summary, a number of factors must be taken into account when considering the permissible dynamic forces arising from manual materials handling. These factors include the task procedure, the moments generated by the working posture and load magnitude, and finally, the movement path which may be symmetrical or asymmetrical (Andersson, 1985).

HUMAN GAIT UNDER LOADED AND UNLOADED CONDITIONS

Bipedal gait, as described by Murray (1966), involves the smooth and co-ordinated movements of all the body parts, and can be considered as a total movement pattern involved in displacing the body. It is, however, a motor pattern that has to be learned and there is general agreement that at about age five the development of mature walking skills have been established (Sutherland, 1980). The term upright bipedal gait essentially describes an action in which the body is supported and balanced in an upright position, while at the same time stepping movements are executed. Lower extremity movements involve producing forces of propulsion (in a downward and backward direction), and of supportive restraint (in a downward and forward direction). The maintenance of balance must be achieved at all times, even when only small parts of one foot are in contact with the ground and the function of the limb is changing from supportive to propulsive in nature. Finally, the mechanics of normal stepping allow the foot (having just comleted the propulsion phase) to pass the contralateral limb without contacting the ground.

Normal gait involves the completion of a cycle of events. The gait cycle is often described in terms of the time taken to complete two successive heel strikes of the same foot. In this cycle there are two periods of single stance and two of double support. When one limb is in the single support phase, the other limb is in the swing phase and at the completion of the swing phase the swinging limb joins the other limb in double support. The double support period may be subdivided into two sub-events: the forward limb experiencing the braking mechanism (braking double support) and the rear limb experiencing propulsion (thrusting in double support). In summary, lower-limb excursions involve periods of single support, double support, swing, braking mechanisms and thrusting mechanisms.

The speed of walking is a product of the step length and the cadence chosen. Thus if cadence (stepping rate) is increased and step length (the horizontal distance along the vector of progression) remains constant or increases, velocity would increase. Conversely, if stride length and cadence decrease, or if only one of these parameters decreases while the other remains constant, velocity will diminish. Murray (1966) suggests that the mean velocity chosen for free speed walking is approximately 1.51 $m.s^{-1}$. (Pierrynowski <u>et al.</u>, 1980 and 1981) studied subjects at walking speeds of 1.54 $m.s^{-1}$ and 1.53 $m.s^{-1}$, while other authors suggest that velocity is best analysed in relative terms, and suggest that free speed velocity is approximately 0.8 $statures.s^{-1}$(Rosenrot <u>et al.</u>, 1980; Charteris <u>et al.</u>, 1986).

As suggested earlier, human bipedal gait includes a multiplicity of movements in order to achieve smooth linear progression. Included are cyclic movements of legs, hips, trunk, arms and head which together provide smooth functional movement and the balance needed to maintain the upright position. a brief description of movements of the various body parts will illustrate the complex integration of movements which occurs in the gait cycle. The movements of the lower extremities include phases of flexion and extension of the ankles and the knees which occur in a complex double wave action (Murray, 1966). Movements at the hip include transverse plane rotation as well as patterns of flexion and extension in the sagittal plane. Trunk movements also occur in the gait cycle and consist of twisting movements in the opposite direction to those of the pelvic girdle. These movements are about the vertical axis and occur in the transverse (horizontal) plane. Arm movements form part of the normal gait pattern. Flexion and extension of the elbows as well as the shoulders are present in normal walking and this reciprocal movement can be seen to be present in children at only 18 months (Sutherland, 1980). Finally, the head and neck execute vertical, lateral and forward movements during each walking cycle, the lateral and vertical maxima occuring when the body attains full height in single support, and the greatest forward velocity of the head is measured immediately prior to heel strike.

The smooth movements achieved in normal gait include those responsible for translocation and those complementary movements used for counterbalancing purposes. There is, however, an extensive range of comfortable walking speeds and varied individual dependence on those movements used for counterbalancing purposes (Murray, 1966). Many of these movements may be disturbed under loaded conditions producing movements which are less smooth and which produce a robot-like progression (Murray, 1966). Many different methods have been used to record and analyse the various aspects of human locomotion (Rosenrot, 1980). Recently, however, there has been the tendency to describe human gait by the analysis of the temporal and distance kinematics, either by employing foot-switch technologies (Rosenrot, 1980; Charteris et al., 1986 and 1988; Wall et al., 1976 and 1978), or by using cinematographic technologies (Kinoshita, 1985; Martin and Nelson, 1986). The benefits of using foot-switch technologies include the ease of data collection and reduction, minimal or no disturbance of the subject's ease of walking, and the wide variety of measured and derived parameters obtainable, together with its suitability for detecting fine changes in any temporal or distance parameter of normal, pathological and loaded gait.

Although load carriage cannot be considered as a pathological condition, changes away from the normal patterns of gait under loaded conditions have been observed. Furthermore, as load increases there appears to be a greater tendency for aberrant gait patterns to develop (Kinoshita, 1985; Martin and Nelson, 1986; Charteris et al., 1986). Information pertaining to changes in locomotory responses to hand-held load carriage has been neglected in the past, although work has been provided by Legg (1985), on hand-held load carriage, and by Legg and Mahanty (1985), on other load carriage methods. Both the above studies considered physiological responses rather than locomotory changes in response to load carriage. Typical of kinematic changes under increasing load include a reduction in stride length, swing time, single support, and the braking mechanism, while increases are seen in cadence, double support time, and the thrusting mechanism (Kinoshita, 1985; Martin and Nelson, 1986; Charteris _et al._, 1986). Kinoshita (1985) acknowledges that different results may be observed in certain kinematic parameters (notably the support times) when comparison is made between fixed speed and preferred speed load carriage protocols.

Many load carriage studies have used loads of the approximate magnitude of 40% of body mass for continuous load carriage, and 50% of body mass for occasional or intermittent load carriage. In other studies responses to loads ranging from 50 to 100kg have been reported (Legg, 1985; Grandjean, 1980). In the industrial setting certain chemicals and grains are packed into bags of either 50 or 100kg, thus giving the workers a limited opportunity for preferred load selection. African headloaders have also been observed carrying as much as 70% of body mass (Maloiy _et al._, 1986), and Legg (1985) makes reference to loads of up to 100kg being carried using "A-frame" baskets. Despite being aware that hand-held carriage methods are the most common for transporting loads, little has been done in regard to the effects that different methods of hand-held load carriage have upon the locomotory kinematics. Brief reference has, however, been made to the manner in which hand-held load carriage inhibits the normal functioning of the upper body's compensatory movements, resulting in impedence of lower limb excursions, and imposing the adoption of sub-optimal postures necessary for counterbalancing the load. Martin and Nelson (1986) suggest that males and females respond differently to set load carriage tasks. They contend that for allometric reasons females (being smaller) responded more dramatically to the absolute loads imposed (as a greater mass relative to body mass was carried) by taking smaller stride lengths and walking at faster stepping rates to maintain the same walking velocity.

THE ENERGY REQUIREMENTS OF DIFFERING LOAD CARRYING METHODS.

Pierrynowski et al. (1981) and Gordon et al. (1983) conclude that when loads exceed approximately 45% of body mass a disproportionate rise occurs in the energy required to continue the task. By-and-large, research into load carriage concerns optimising carriage tasks and consequently the search has been to establish the efficient and safe form of load carriage (Zerbib et al., 1983). Work by Legg (1985) in this field reveals that the cost of carrying 30kg 1km at 5 $km.h^{-1}$ is affected in the following manner: The most efficient method is that of a balanced double pack, followed in descending order by a head basket, backpack, the Sherpa (head strap) carrying method, a yoke and finally, bimanual load carriage. It is also pointed out by this author that, in general, heavy loads should not be coupled via small muscle groups, but rather should be associated with large muscle groups and should be held as close to the trunk as possible. Loads, when carried in the hands, require static muscle contractions (which often require large percentages of maximal voluntary contractions (MVC)) which consequently induces rapid muscle fatigue, while also restricting upper-body movement (Grandjean, 1980; Legg, 1985). Despite people being aware that hand-held load carriage is particularly fatiguing, for reasons which include the restriction of blood supply and rapid toxic waste formation under high %MVC conditions produced in the working muscle, the convenience of hand-held load carriage is chosen for short carrying distances.

PSYCHOPHYSICAL PERCEPTIONS AND PREFERRED LOAD SELECTION

Psychophysics has as its central focus the quantification of the subjective experience of exposure to a particular physical stimulus. Consequently it makes use of methods which allow for comparison of individual experiences of differing intensities of either a specific sensory input, or of multiple sensory inputs. Recently the use of psychophysical techniques has proliferated and such techniques have come to be recognised as essential contributors to the development of MMH guidelines (Snook, 1985). Snook was concerned to identify the various benefits and shortcomings of the psychophysical method of establishing acceptable working conditions. Considered as benefits are observations that:

1. Industrial work may be simulated reliably.
2. The values obtained are highly repeatable on a test-retest basis.
3. The chosen work-rates fall within the range of outputs considered as being economically viable.
4. Tasks that occur on an intermittent basis can be studied.
5. There appears to be a relationship between task ratings and low-back pain.

The shortcomings of the psychophysical method, as presented by Snook (1985), include:

1. The subjectiveness of self-reporting protocols.
2. The insensitivity of the psychophysical method to the ability to distinguish between injurious types of stress and non-injurious types.
3. The inaccuracy of these methods when considering high-frequency lifting or carrying tasks.

Two questions, however, predominate when psychophysical methods are used to assess industrial work loads. One involves determination of the maximal acceptable load (acceptable in structural and psychological terms by those involved in the activity) applicable to a specific task; the other the perception of work intensity claimed by a worker in response to a pre-set task. In respect of the first question, much has been done in the setting of guidelines for lifting and carrying tasks to comply with structural and psychophysical acceptability (Snook, 1978; NIOSH, 1982; Ciriello and Snook, 1983; Mital and Manivasagan, 1983). The load-selection approach considers the preferential choice of loads at given work rates, thereby accommodating the worker's physical perceptions and capabilities. The structurally based guidelines prescribe limits to the permissible forces generated in lifting tasks on the basis of epidemiological data and known stress-inducing limits.

Rating scales, particularly that of perceived exertion, have been used to a large extent to rate the intensity of physical work. Borg (1970) has developed a perceived exertion scale which consists of verbal anchors describing increasing work intensities on a scale from 6 to 20. Although this scale was developed for use in rating work on a cycle ergometer , Gamberale (1985) concludes that the Borg Perceived Exertion Scale is the most frequently used scale for the rating of physical work in general. Since its inception the Borg scale has undergone continuous amendment and wider application and is considered today to cover metabolic activity (of short and long duration) and neurological factors in response to physical activity (Rejeski, 1981 and 1985). Work done by Ekblom and Goldberg (1978, cited by Pandolf, 1978) in determining whether local or central exertion factors are dominant for particular types of physical work, suggests that work involving small muscle groups will be dominated by ratings of local exertion. The use of small muscle groups is prevalent in industry, where MMH tasks are largely achieved through the use of the arms. Work involving large muscle groups, on the other hand, would be dominated by ratings of central exertion. Furthermore, Robertson (1982) postulates that local exertion cues will dominate over central cues in the first 30s of dynamic exercise, and hence suggests that duration and intensity of exercise need to be considered when partitioning ratings of perceived exertion (RPE) into local and central categories. Carton and Rhodes (1985) conclude that the perception of physical strain in the muscles will predominate over the perception of effort at low work levels, while at high work levels the concentrations of blood lactate will pose a greater influence. Carton and Rhodes stress the fact that individual psychophysical perceptions are influenced by factors such as physical conditioning, task experience, sensory acuteness, and individual pain thresholds, and that these factors should be considered when assessing psychophysical ratings.

The extensive application of psychophysical indicators, particularly those of perceived exertion, can be seen in clinical, sporting, rehabilitational and occupational settings. Noble (1982) cautioned that, when psychophysical methods are selected for clinical application, they should be appropriate to the task being examined and furthermore, that development, research and training in the domain of psychophysics must be encouraged in order to maximise the known and potential benefits of the findings achieved in this field.

Knowledge of how to optimally utilise human resources is of concern to all those involved in production and to society in general. Exceeding the physical and psychophysical limits of labourers is detrimental for both the employer and employee. Chaffin et al. (1978) advocate the concept of pre-employment strength testing for jobs involving physical exertion. They also suggest that isometric simulation of the task should be conducted, and those who exceed the requirements should be considered for MMH selection. This approach might be useful when considering very specific tasks in the industrial context. However, the majority of lift-and-carry tasks are done on an intermittent or occasional basis by virtually the entire spectrum of the population and not only by those physically adept at MMH. Chaffin et al. (1978) have offered some idea of categories of physical stress as follows: Under half of maximal isometric strength: "under stressed"; over half and to maximal isometric strength: "considerably stressed"; and above maximal isometric strength: "overly stressed". Certain groups of people, for example Sherpas and African headloaders, are able to carry abnormally heavy loads, due largely to the fact that they have been taught how to carry and also are involved in carrying from early ages. The two carrying methods performed by the above-mentioned groups incorporate the principle of progressive resistance training, which is known to strengthen musculature (McArdle et al., 1986), in addition to the teaching of optimal carrying techniques, which has been shown to increase efficiency and decrease the risk of injury (Broer and Zernicke, 1979). Grandjean (1980) proposes that, by adhering to a few practical guidelines, the stress of occasional and frequent lifts or carries can be reduced.

These rules include:

1. Lifting the load with the spine as straight and upright as possible and having the knees well flexed.
2. Reducing as far as possible the distance between the base of support and the centre of mass of the load in both lifting and carrying.
3. Attempting to couple with the load at waist to chest height.
4. While handling the load, attempting to maintain the spine in a straight vertical position.

Success of these rules requires that one is familiar with the techniques and can recognise excessive exertion and the use of bad lifting techniques through proprioceptive feedback.

TASK CHARACTERISTICS

A great variety of MMH tasks exist in the daily routines, work patterns and recreational activities of the individual (Broer and Zernicke, 1979). Bearing in mind that individuals are often involved in load-carrying activities (Kinoshita, 1985), it has been suggested that a number of problems should be addressed when approaching any load carrying task, and these may be summarised as follows:

1. Choosing a posture in which efficient coupling can take place so that the lifting force may be as vertical as possible.
2. Maintaining optimal body balance and correct lifting posture.

3. Being aware that the initial lifting force may require a component of diagonal lift as well as vertical lift.
4. Ensuring that, as far as possible, the lifting force should be generated by the strong leg muscles.
5. Employment of any lifting techniques whose effect is to lighten the burden, such as the use of momentum to contribute to the lifting force.

The physical properties (those of mass, size, shape, density and consistency) of a load, together with the existence of coupling agents such handles or assistive devices, determine the ease and specific method with which the load may be transported. The addition of mass in whatever form will result in additional biomechanical and physiological stress to the body. Gordon et al. (1983), in a study comparing load carriage with grade walking on a treadmill concluded that the imposition of increasing load or grade brought about a linear increase in heart rate and RPE, although for the loaded condition the heart rate and RPE values were relatively elevated. Pierrynowski et al. (1981) also found that the addition of load in the form of a back-pack (for the additional masses considered) produces a loading distribution similar to that of greater fat deposition and as such the mechanics and movements of the various body parts are not influenced significantly. Even under optimal loading Gordon et al. (1983) established that, for reasons relating to the posture changes needed to balance the load, and the resulting increased range of muscle action, due to forward inclination, load carriage imposed relatively greater strain on the cardiovascular system than grade walking, as seen in a disproportionally high heart rate relative to the measured energy demands (%VO_2) for those tasks.

The principle that load produces a linear increase in energy demand is not in question, however, as Legg (1985) has shown that when different methods of load carriage are employed the energetic efficiency of such methods differs widely. Thus, carriage of increasing loads in the hands is likely to result in initially higher energy requirements for the same load task and possibly greater relative increases (until maximal values are reached) in oxygen consumption as load increases further. Additional loads as seen by Gordon et al. (1983) resulted in inflated ratings of perceived exertion when compared to grade walking, and they suggest that the increase in strain in the relevant muscle groups was responsible for this finding.

The shape of the object has great influence on how the load may be transported. Awkward shapes require a carrying strategy that enables efficient locomotion as well as the ability to conserve energy. An example of how awkward, heavy loads may be accommodated is provided by African headloaders who carry objects of approximately 160% of stature and up to 70% of body mass (Charteris et al., 1986; Maloiy et al., 1986). Other awkward shapes that have been examined include various military weapons (Legg, 1985), which are hand-held.

Everyday examples of loads of awkward shape include the portage of household appliances, such as fridges, stoves, television sets and furniture. Objects such as those described above are often of such a shape, size and mass that more than one person is required to handle the load (for purposes of safety, efficiency and practicality). Furthermore, objects such as these often restrict forward and downward vision of the individual and consequently require a more cautious stepping action. Cautious progression cannot be executed at the same speed and efficiency as unresticted load carriage and when this type of walking is coupled with loads that restrict lower limb excursions and force carrying postures that may be particularly uncomfortable but unavoidable, the cost in energy terms and biomechanical strain may be high. However, there appears to be no substitute for the versatility and carrying ability of man, especially when loads have to be manipulated in restricted space and over different surfaces and gradients. In particular, large objects are more difficult to handle. Sizable objects, even if they have a light mass, present problems of manipulation, restricted vision, coupling, carrying method and the possible carriage postures assumed. For this type of load the coupling point may be distant from the centre of mass of the body, while the centre of mass of the load may be far from the body. Thus large effort arms are created which in turn increase the muscle activity necessary to resist the forward flexing moment, assuming that the load is carried using a frontal carriage method (Broer and Zernicke, 1979).

Other physical properties of a load include its density and consistency. Dense objects tend to be heavy, especially if they are large, and should be carried as close to the trunk as possible (Legg, 1985). Load consistency, however, can be divided into a number of categories, the most simple of which has an even density of content distributed throughout the container (for example a packing case of tinned food). The second category can be described as a load of uneven density or offset mass distribution, as described by Garg and Saxena (1980) and Mital and Manivasagan (1983). In this case, the distribution of mass is unable to shift (for example a softdrink crate with full bottles located on one side and empty ones on the other). When loads of this type are carried the MAL is significantly reduced and it is preferable to load the preferred or stronger hand with the load offset towards that side. The final category consists of a load that has shifting properties, where movement of any sort will tend to shift the distribution of the load. Fluids which do not fill their containers and unrestrained solids are examples of this type of load, whose form is maintained by the restrictions of the container used to transport the load. Fluid viscosity may also influence the rate at which the load is able to alter its centre of mass; more viscous fluids resist equilibrium disturbances better.

LOAD COUPLING

Many different load carrying methods exist, but the manner in which loads may be coupled to the body is restricted to one of two categories or the use of both simultaneously. The first category may be described as natural loading, wherein the load is coupled to the body without assistive devices. Generally natural loading requires the use of the arms and hands either ot grip, hold, or balance the load in such a way that steps may be taken and balance maintained. The second category calls for the use of assistive devices such as back-packs, double packs, yokes and flack jackets, to name a few. All these devices are designed to improve the man-load couple and consequently improve efficiency by coupling the mass to large muscle groups (Garg *et al.*, 1980; Legg, 1985). Combinations of these two loading categories frequently arise, especially in military circumstances where clothes, ammunition and provisions are carried in specially designed packs, while weapons are usually carried in the hands.

Oguro (1982) notes that hand- and arm-held load carriage methods are the most frequently encountered forms of load carriage in everyday situations. Due to the fact that the hand forms an excellent coupling agent and also that its versatility is unparalleld in strength and sensitivity, its value has been greatly exploited in industry as well as in domestic situations. The performance of the hand as a coupling agent can be greatly influenced by the texture of the coupling surface together with the existence, shape and position of hand placements or handles (Drury and Pizatella, 1983). Drury (1985) and Drury and Pizatella (1983) recommend that the coupling surface should be non-slip in texture, although not of an abrasive nature, as this may graze the hand and limit grip adjustment. These authors limited their research to a consideration of the texture of handles. The need exists, however, for the improvement of the coupling surfaces of the many containers deviod of handles. Thought has been given to the placement of the hands on box-like containers (Drury and Pizatella, 1983; Deeb et al., 1985; Drury, 1985). It was found that a wide variety of hand positions were preferentially selected. It was concluded, however, that hand positions should maximise the horizontal and vertical stability of the container. This can be achieved by placing the hands in a diagonally opposite position on the box.

The hand is able to perform three types of coupling actions (Drury, 1985). The first of these is the hook grip, where only the fingers are curled around the object. The second action can be described as the power grip, in which the thumb and the fingers are used for gripping, although the thumb exerts force on the opposite side of the handle to the fingers and along the plane of the palm. The third coupling action described by Drury (1985) is the precision grip, where the object is pinched between the fingers and the opposing thumb. Drury (1985) failed to mention the coupling action where both hands are used in opposition to hold an object between them by means of inward pressure. In this case this is the sole means by which the container is held; none of the above-mentioned actions are employed. While each of the coupling actions described above have benefits under different conditions, the hook grip appears to be the most commonly employed method as many containers only allow for this grip since edges or handles provided for a coupling point do not allow sufficient hand clearance. The power grip is the most effective hand coupling when forces are high. However, this grip lacks precision and control. The precision grip is useful in fine manipulative work, but heavy loads cannot be coupled efficiently using this method (Drury, 1985).

Clearly optimising hand-load coupling by using handles and selecting the optimum sites to place these devices allows greater forces to be generated. The presence of handles has been seen to permit greater loads to be lifted and heavier MALs to be selected, while at the same time lowering the energy cost, heart rate response and ratings of perceived exertion compared to the same task using containers without handles (Drury and Pizatella, 1983; Deeb et al., 1985; Drury, 1985). Finally, it has been suggested that when handles are provided, they should be functional rather than decorative in nature and as such should provide an optimum coupling (Drury, 1985).

Increasing use of assistive devices for load carriage has prompted research into the refinement of carrying techniques and equipment (Kinoshita, 1985; Legg and Mahanty, 1985). The underlying principle of the use of assistive devices in load carriage is to optimise the mechanical and energetic efficiency of the designated task. To achieve this aim concern must be given to the comfort and location of the coupling sites. Comfort may be enhanced through the use of padded contact surfaces, while distributing the coupling force over as large an area as possible. The energetic cost of carrying loads is most effectively accommodated by attaching the loads to large muscle groups which are not subject to rapid fatigue (Garg et al., 1980; Legg, 1985). In particular, coupling on the hip area distributes a load over a considerable area where large muscle groups are present, and also places the point of load attachment below the lumbar area and therefore does not contribute to spinal pressures. Techniques such as this are mechanically and energetically effective, but suffer from inflexibility in regard to the type of task that can be carried (awkward shapes as well as differing physical properties may be problematic), and also the type of task that can be effectively accommodated. Generally assistive devices are useful for tasks that continue for a lengthly period of time, but owing to their specific designs, are limited in their use for short duration intermittent everyday load carriage tasks.

ELEMENTS OF PHYSICAL WORK

Work, by definition, is equal to the product of force and distance. Energy is required to bring about the displacement of any object or to maintain an equal and opposite force to achieve dynamic equilibrium in the absence of movement.

Everyday load carriage tasks, whether they are occupational, recreational or of a routine nature, all involve physical work. The energy requirements for the accomplishment of those tasks depend on the frequency, intensity, nature and duration of the activity. These four factors can vary considerably. However, their combined action should not exceed either structural or physiological limits. The mean upper physiological limits appear to be around 30% to 40% of an individual's maximal oxygen uptake for an eight hour working day (Åstrand and Rodahl, 1977), while at the same time, load masses as suggested by Legg (1985), should not 40% of body mass for repetitive tasks. In the industrial setting work is normally required for an eight hour period, which can, therefore, be regarded as an independent fixed variable. Furthermore, as discussed above, energy expenditure should not exceed 40% of VO_2 max and the mass of the load should not be greater than 40% of body mass. These two factors may also serve as independent constraints. The nature of the load being handled should also be considered, as awkwardly shaped loads may impose high biomechanical strain and increase energy expenditure. The remaining factor, frequency, is constrained in its ability to vary owing to the suggested limits of load mass, levels of oxygen consumption, forces generated by shape and size of a load, and the need to work for an eight hour period. Thus, work frequency settings must accommodate all the above constraints while not exceeding suggested maximal limits.

CONCLUSION

The carrying of loads, especially by hand is a task performed on an everyday basis by the vast majority of people.

Although much research has been conducted in the fields of locomotory kinematics, manual materials handling, optimising the energetics involved in manual work, less emphasis has been given to considering the biomechanical, physiological and psychophysical effects that various everyday hand-held load carriage tasks have on individuals. Lack of knowledge in this field is particularly distressiing when one considers the number of tasks that involve hand-held loading as well as the known detrimental conditions that arise from overexertion. The increasing number of reported cases of lower back pain syndrome bear testimony to the fact that much needs to be done in order to reduce this epidemic problem. Deeb et al. (1985) point out that the best lasting solution to addressing the mismatch between man and the load is to redesign the task and load object to accommodate the capacities of the man. Furthermore, because manual materials handling involves human participation, factors such as progressive work fatigue, individual pain tolerances (conditioned workers may tolerate higher levels of pain than non-conditioned workers), and the reassessment of pre-employment strength tests should be considered (Griffin et al., 1984). Finally, without knowledge of a prophylactic nature which addresses the problem of lifting and carrying techniques, loads (especially in the home situation) may at times exceed the capacities of the individual and expose the individual to stress-related risks (Broer and Zernicke, 1979; Grandjean, 1980).

CHAPTER 3

EXPERIMENTAL METHODS AND PROCEDURES

CHOICE OF SUBJECTS

A sample of 10 male and 10 female volunteers between the ages of 18 and 30 was obtained from the student population at Rhodes University. Subjects were not occupational load carriers. However, all had previous experience of the carrying tasks required through participation in either a test-retest reliability study (Nottrodt and Manley, under review), or a comparative study between males and females (Nottrodt and Manley, under review). Both studies investigated the psychophysical concept of MAL, as well as the kinematics of gait associated with load carriage. Subjects chosen for the present study were not given any incentives to participate, nor were they required to base their work rate on an eight-hour working day, as was done by Snook (1978) in a similar study.

PERSONAL INFORMATION

The age, mass, stature, leg length, arm length, chest and abdominal girths, hand dominance, biiliac and biacromial widths and right and left hand-grip strengths were recorded in the first data collection session. These data were used to identify whether pertinent structural or functional differences existed between males and females.

Anthropometric differences might have accounted for differences in performances. A listing of the anthropometric data collected appears in Table II All these measurements were conducted according to the methods laid down by Carter (1975)

PILOT TESTING

For this study pilot work was done in the following fields: 1) Establishment of the reliability of the psychophysical concept of MAL for a number of load-carriage methods; 2) Establishment of the reliability of the measurement of the gait parameters chosen to describe locomotion; 3) Establishment of the reliability of the anthropometric data collection techniques.

In all cases reliability was assessed on a test-retest basis. For fields one and two above the MAL and kinematic data were analysed using a two-factor analysis of variance (ANOVA) with repeated measures on both factors (Ferguson, 1981). The factors comprised: 1) the two test sessions; and 2) the method of load carriage. Where differences between carrying method and load existed, a Sheffé *post hoc* analysis (Ferguson, 1981) was employed. The confidence level for the ANOVA was selected as $p<0.05$.

Pilot work confirming the reliability of acceptable loads and locomotor patterns for this study was conducted by Nottrodt and Manley (under review). Both MALs and locomotor patterns were found to be reliable on a test-retest basis.

Reliability of the anthropometric techniques was confirmed by conducting a related Student's t-test (Ferguson, 1981) on the measures. Five subjects were involved on a test-retest basis and no significant differences were found. It was concluded that the anthropometric data collection methods were reliable.

Reliability of data reduction concerned the accuracy of digitizing kinematic patterns as recorded on physiograph paper. Statistical analysis by means of a one-way analysis of variance (ANOVA) with repeated measures (Ferguson, 1981) revealed no significant differences ($p<0.05$) between repeatedly digitized patterns.

RESEARCH PROTOCOL

Subjects participated in four test sessions, each of approximately 40 minutes duration. They were asked to report well rested and not suffering from any physical impairments, such as sprains or strains. In session one anthropometric and strength data was collected, the details of which appear under the section entitled Personal information. The second session involved the establishment of maximal acceptable loads (MAL) and absolute maximum loads (AML) for the four carrying methods. There were two lateral and two frontal carrying methods, as follows: 1) Unimanual; carriage of a load in the dominant hand at the side; 2) Lateral, bimanual; carriage of separate loads, one in each hand pendant at the sides; 3) Frontal, flexed; carriage of a load with both hands in front of the body with the elbows flexed 90°; 4) Frontal, extended; carriage of a load using both hands, with the extended arms pendant in front of the body. These portage methods were identical to those described by Nottrodt and Manley (under review) and similar to the two load carriage methods investigated by Snook _et al._ (1970), Snook and Ciriello (1974), Snook (1978) and Ciriello and Snook (1983).

Testing sessions three and four involved the collection of data pertaining to 17 walking conditions, 16 of which were load carriage conditions and one an unloaded condition. The 16 load conditions comprised MAL and three incremented loads in excess of the MAL for the four load carrying methods. All subjects performed the unloaded walking condition first, followed by the loaded conditions, randomised as follows: One of the four carrying methods was selected and paired with one of the four load conditions. This randomised pairing was continued until the possible combinations were exhausted.

The Establishment of MAL and Increments Above MAL

For each method of load carriage subjects were asked to establish their MAL over a 10m walking distance. At each end of this distance subjects were permitted to add or remove lead shot from the container being carried, and to continue this process until they were satisfied with the mass of the container. Sufficient rest periods were provided in the MAL selection sessions in order to minimise the risk of cummulative fatigue which may have interfered unduly with the carrying performance and choice of loads. The containers were pre-weighted (up to a maximum of 10kg) using a false bottom in the container.

Presentation of weighted containers in this manner ensured that subjects were not given standard starting loads on each occasion for each method and eliminated visual cues which might have biased loading. Once the MAL for each carrying method had been chosen the mass of the container was measured.

Subjects were also required to establish AML limits for each carriage method, over the 10m walking distance. A procedure similar to the method used for establishing MAL values was employed. Subjects added lead shot to the containers until the point was reached where they felt they could no longer carry the load for 10m. Sufficient rest periods were provided between incrementation to ensure the complete recovery of the subject. While subjects carried incremented loads safety spotting was provided to prevent injury in the event of the load slipping or falling.

For both MAL and AML the containers were placed at such a height as to eliminate the necessity of first lifting the load. It was stressed that subjects should consider that the MAL and AML values should represent a single carry in a working day.

Habituation.

Minimal habituation for this study was required as the equipment used to collect the desired kinematic data did not restrict movement, and the mass of this system could be considered negligible. All the subjects chosen for this study had experience in carrying loads, having previously participated in a similar load carriage study (Nottrodt and Manley, under review). Before any data was collected subjects were made thoroughly familiar with the four load carrying methods and how to rate perceptions of exertion.

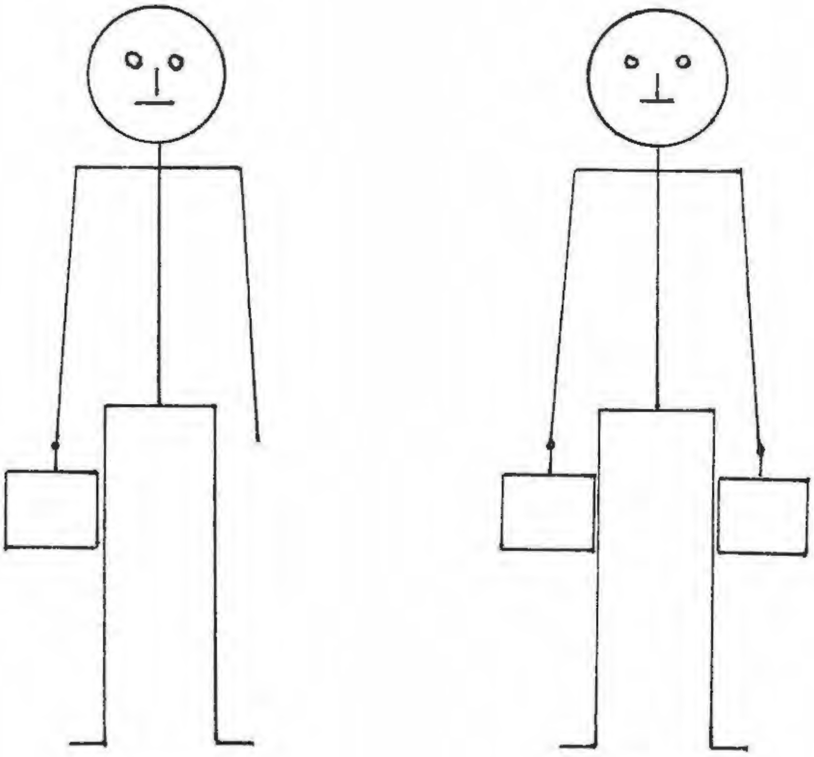
Selection of Experimental Conditions

Seventeen conditions were assessed in this study. The 16 loaded conditions comprised four carriage methods each under four incremented mass conditions. The experimental conditions are summarised in Table I below.

Table I: Summary of the load carriage conditions. Numbering signifies the test number of the combination of carriage method (rows) and incremented loads (columns).

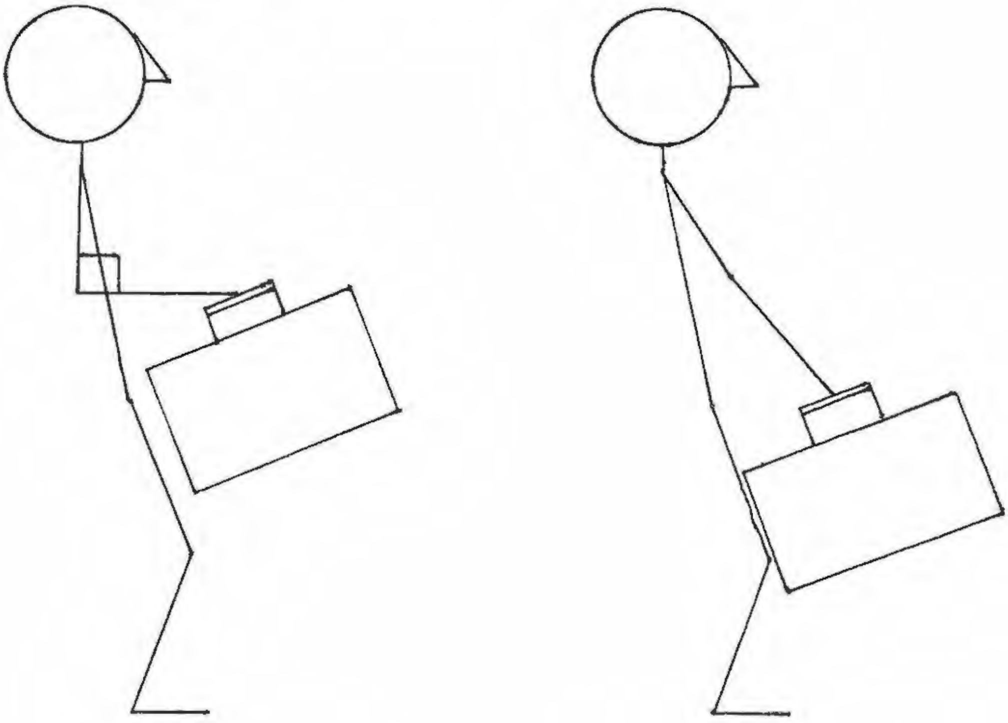
			Incremented Loads			
		No Load	P	P25	P50	P75
	Normal Walking	1				
Lateral	Unimanual*		2	3	4	5
	Bimanual		6	7	8	9
Frontal	Flexed		10	11	12	13
	Extended		14	15	16	17

* Load carried in the dominant hand.



Unimanual Bimanual

Figure 1: Lateral load carraige methods.



Flexed Frontal Extended Frontal

Figure 2: Frontal load carriage methods.

Three incremented loads above maximal acceptable levels were imposed as conditions. These were obtained as follows: For each carrying method and for each subject the range between the MAL and AML values was calculated. This range was then multiplied by 0.25, 0.5 and 0.75, and each of these products was added to the individual's MAL value.

Mathematically stated, the four loads under investigation were as follows:

1. Preferred load + (range)0 [P] = MAL + (AML - MAL)0
2. Preferred load + (range)0.25 [P25] = MAL + (AML - MAL)0.25
3. Preferred load + (range)0.5 [P50] = MAL + (AML - MAL)0.5
4. Preferred load + (range)0.75 [P75] = MAL + (AML - MAL)0.75

Incrementation on this basis ensured that all subjects were set at the same relative percentages of the range in excess of MAL values, thereby accounting for variations in the individual choice of MAL values. Furthermore, it ensured that MAL values formed part of the incremented loads, as an attempt to include the psychophysical perception of MAL in the loads to be lifted. Finally, incremented loading in this manner ensured that loads exceeded MAL values but fell beneath individual AML values, thus providing a safety margin of reserve physical capacity in each case. The load increments considered in the present study differed from those based on body mass (Pierrynowski, 1981) or absolute lift capacities (Legg and Pateman, 1985) by considering a range of loads identified as greater than the MAL value.

In all 17 conditions subjects freely chose their preferred walking speeds. Separate containers were used for the lateral and frontal carriage methods, their dimensions being as follows: For the container used in the unimanual (uni) and bimanual (bi) tasks, 45.5 × 20.5 × 18.5cm; and for the container used in the frontal tasks (flx and ext), 46.5 × 37.5 × 27.5cm.

Both containers had handles which met with the design standards recommended in Mil - STD 1472C (1984). The walking distance required for all conditions was 10m and subjects walked upon a metal foil walkway. This distance was chosen because it typified short-to-medium range load carriage activities encountered in everyday situations (Zerbib et al., 1983). At the same time it exceeded, and thereby encompassed the shorter distances which have been investigated in the past (Snook, 1978; Drury et al., 1983; Celentano and Nottrodt, 1984).

To ensure that the preferred speeds chosen for the 17 carrying conditions were typical of normal responses to the loads carried, subjects were asked to walk the 10m distance three times for each condition. For these walking trials the range of speeds was not allowed to exceed approximately 5% of the mean. A fourth trial was then conducted during which the kinematic data were collected. The speed chosen for the fourth trial was required to be within 5% of the mean of the first three trials. Where this requirement was not met a fifth trial was conducted. Immediately on completion of the test trial psychophysical ratings of perceived exertion (RPE) were recorded. Between all walking trials subjects were at liberty to rest, and only commenced the next walking trial when they were ready.

DATA COLLECTION AND REDUCTION METHODS

Gait Kinematics

All parameters measured with respect to the gait cycle were collected over the central six metres of the 10m walkway. A photocell-triggered timing system was used to determine the speed used by the subjects to walk the central six metres. Using techniques similar to those reported by Wall et al. (1981), Nottrodt et al. (1982) and Charteris et al. (1986), several temporal and distance kinematics of foot-floor contact patterns were measured. The foot-floor contact patterns were recorded by using strips of self-adhesive tape (which served as switches) affixed to the heels, balls and toes of the subjects' sock-covered feet. The conductive tape strips were connected to a light-weight function box located on a canvas belt worn by the subject, and also to a power supply via an umbilical cord on a friction-reducing track. A multi-channel biological recorder recorded resistance changes in the system when the conductive tape strips signalled contact with the foil walkway. Signals from the three foot switches on each foot were recorded on a moving chart with respect to time (the paper speed of the recorder was 5 $cm.s^{-1}$) and were then used to determine the contact phases of the foot in the gait cycle.

A sonic digitizer was used to enter the temporal data into an Apple IIe microprocessor for reduction. Three to five strides were digitized and the data averaged for each condition.

In addition to walking speed this study examined the following: Cadence; stride time; stride length; total support; double support; relative speed; and the support-to-swing ratio. For the purposes of this study these parameters were analysed in the following manner: Preferred speeds were measured in $m.s^{-1}$; cadence (or rate of stepping) in $steps.min^{-1}$; stride time in seconds; and stride length in centimetres. One stride was defined as an event sequence between two successive switches of the same side. Total support was recorded as the time from heel-strike to toe-off for that foot, and expressed as a percentage of stride time and averaged for both left and right feet over the number of strides considered. Double support was the time spent on both feet simultaneously and was expressed as a percentage of stride time. Relative speed was measured in $statures.s^{-1}$. Its inclusion was considered to be useful in that size differences between subjects were factored out. The support-to-swing ratio was recorded as a dimensionless ratio which could be considered as a single descriptor of locomotory trends.

Psychophysical Ratings

Subjects were asked to rate perceptions of overall exertion and to identify and rate anatomical regions where localised

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exertion was felt. This applied to all load conditions. The ratings of overall and local exertion were identical to those used by Nottrodt (in preparation), in a study on stoop walking. In each instance the Rating of Perceived Exertion Scale (Borg, 1970) was used (see Appendix A). Borg's lower limit of six would correspond with the perception of effort while standing calmly unloaded; 20 would represent maximal exertion. In addition to rating local exertion, subjects were asked to identify on an anatomical chart depicting the anterior and posterior views of the human body (see Figure 18) sites where local exertion took place. For easy reduction the anatomical charts were zoned alphabetically.

ENVIRONMENTAL INFLUENCES

Testing took place in the gait laboratory of the Department of Human Movement Studies at Rhodes University. Temperature of the laboratory remained comfortable and did not affect data collection or performance. Daily variation such as diurnal cycles, experienced by the subjects were not accounted for in this study.

SAFETY PROCEDURES

Owing to the potential risk of incremented loading past MAL values, care had to be taken to minimise the possibility of injury due to falls or the dropping of the load. To ensure that the subjects feet did not slip on the foil walkway, socks with non-slip rubber soles were worn. Furthermore, the metal surface was regularly cleaned of dust with a damp cloth to ensure that traction was optimised. The containers used had handles which met with requirements suggested as being optimal (Mil - STD 1472C, 1984) and as such a good coupling between hands and handles was assured. Subjects were also advised that if at any stage the loads became excessive, they were free to stop and put down the loads.

INFORMED CONSENT

Before subjects participated in this study they received comprehensive information familiarising them with the nature and content of the study, as well as the requirements of participation. Benefits and potential risks were clearly defined. It was stressed that participation in the study was entirely voluntary and that subjects were free to leave at any point during data collection if they so wished. A consent form was presented to the subjects before testing. By signing this form subjects gave permission to the researcher to use any data collected for research or publication purposes. Copies of the informed consent can be found in Appendix B .

STATISTICAL TREATMENT OF RESULTS

Statistical analyses for this study required the use of both parametric and non-parametric procedures.

The psychophysical ratings (RPE), choice of loads and the kinematic data (dependent variables) were analysed using a two-factor analysis of variance (ANOVA) with repeated measures on both the independent variables. The independent variables were the load method and the load increment.

The kinematic data were analysed through the use of a one-way analysis of variance (ANOVA) with repeated measures. Kinematic variables for both inloaded and loaded conditions were compared. The independent variables were the set percentage increments, while the dependent variables were the kinematic data resulting from these conditions.

An independent Student's t-test was used to compare the anthropometric data of males and females. A related Student's t-test was used to compare maximal hand-grip strength with the absolute mass carried in the dominant hand.

A chi-squared non-parametric test (Ferguson, 1981) was used to ascertain whether the tally of locally reported sites of exertion changed with increasing load or differing load carrying method.

The 0.05 level of confidence was chosen for all statistical tests. This was retained when Sheffé post-hoc analyses were conducted.

CHAPTER 4

RESULTS AND DISCUSSION

SUBJECT CHARACTERISTICS

Anthropometric Variables

In order to physically compare the male and female subjects a number of anthropometric parameters were measured. Males demonstrated significantly greater values for mass, stature, arm length, biacromial width and chest and abdominal girths than did females. Male lower limb lengths and biiliac widths were not significantly greater than those of the females. The mean age of the males was significantly greater than that of the females.

In light of the fact that most of the anthropometric parameters were significantly different (in all instances males having greater values than females), it is clear that males were bigger and heavier than females in this study and as such demonstrated sexual dimorphism. Stature and other morphological variables are known to influence gait kinematics as well as the performance of strength related tasks (Martin and Nelson, 1986).

Kinematic data recorded in this study clearly revealed that although both sexes chose approximately the same relative speeds for all conditions, in absolute terms male walking

Table II: Anthropometric variables.

Lengths (cm); Masses (kg); Strength measures (kg).	MALE	FEMALE	M>F	$\frac{F}{M}$ * (%)	t_o: (t_c = 2.101)	M vs F (Sig. unless indicated)
Stature $\bar{x}$	176.8	166.2	10.6	94.0	4.35	-
S.D.	6.9	3.2				
Lower limb length $\bar{x}$	89.4	85.3	4.1	95.41	2.01	NS
S.D.	4.4	4.6				
Upper limb length $\bar{x}$	77.1	72.7	4.4	94.29	2.85	-
S.D.	4.2	2.4				
Biacromial width $\bar{x}$	40.1	36.1	4.0	90.02	5.07	-
S.D.	1.8	1.5				
Biiliac width $\bar{x}$	27.8	27.4	0.4	98.56	0.747	NS
S.D.	1.2	1.3				
Chest girth $\bar{x}$	95.5	86.4	9.1	90.47	3.82	-
S.D.	6.1	4.3				
Abdominal girth $\bar{x}$	78.0	69.4	8.6	88.97	3.99	-
S.D.	4.5	5.6				
Left hand grip-strength $\bar{x}$	51.6	30.3	21.3	58.72	6.1	-
S.D.	9.5	5.4				
Right hand grip-strength $\bar{x}$	51.8	32.9	18.9	63.51	6.8	-
S.D.	7.6	4.1				
RPI $\left(\frac{\text{stature}}{\sqrt[3]{\text{mass}}}\right)$ $\bar{x}$	42.3	42.7	-0.4	100.9		NS
Age (years) $\bar{x}$	23.9	20.8	3.1	87.3	2.77	-
S.D.	3.2	1.3				
Mass x	72.9	58.8	14.1	80.66	4.23	-
S.D.	8.2	6.4				

* % Dimorphism

velocity was significantly greater than that of the females. Differences in absolute velocity may well be accounted for in terms of the sexual dimorphism noted above.

In general, larger persons are absolutely stronger. Males demonstrated greater MAL and AML values than females, and these differences may be partly due to absolute differences in size, body composition and muscle strength distribution, or psychophysical tolerance to tasks demanding a high percentage of voluntary strength. Anthropometric variables are presented in Table II.

GRIP-STRENGTH

All the portage methods investigated in this study involved retaining a grip with the hands while the body was in an upright posture. Maximal grip-strength values were obtained, and served as a static strength measurement for this study. Female grip-strength values were approximately 62% of male values, indicating that in functional physical capacity there were distinct sex-based differences.

AML values chosen by the males for the unimanual lateral carriage method significantly exceeded dominant hand grip-strength values. The mean AML value for this carrying method for females also exceeded their mean hand-grip strength. Combining both male and female data, AML values were significantly greater than hand-grip values. This finding illustrates the fact that performance is not necessarily easily measured and that measurement techniques do not always

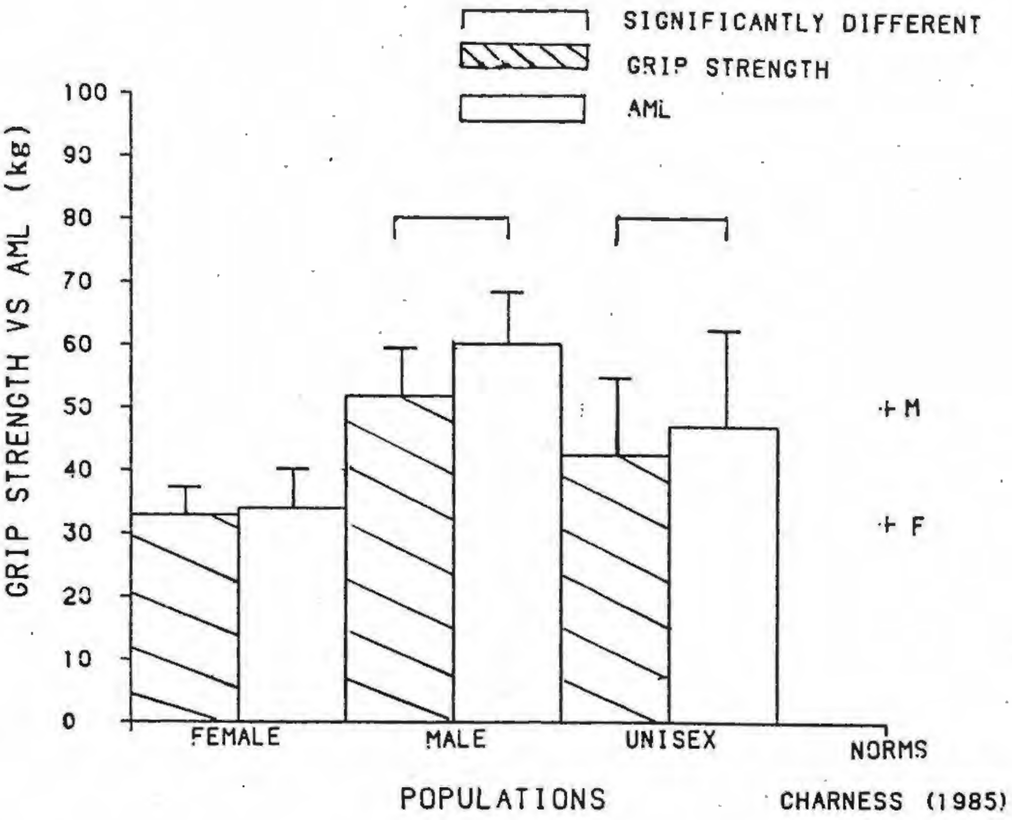


Figure 3: Male, female and unisex grip-strength values.

Table III: AML values versus grip-strength values.

Subject	Grip-strength values			AML values for methods (per hand).			
FEMALES	LGS	RGS	CGS	UNI	BI	FLX	EXT
A	30.2	30.2	60.4	29.0	26.8	13.85	19.05
B	30.6	33.8	64.4	25.9	23.6	13.85	17.0
C	41.2	42.0	83.2	36.3	35.75	23.15	27.0
D	24.2	31.4	55.6	30.0	27.0	18.15	20.0
E	34.2	34.3	68.5	44.0	42.95	20.45	29.75
F	33.2	32.6	65.8	42.2	45.0	24.5	29.5
G	29.6	29.7	59.3	30.9	29.75	19.85	25.45
H	23.4	27.2	50.6	29.5	30.75	17.7	20.65
I	32.2	36.9	69.1	38.6	31.1	22.7	27.95
J	24.4	31.0	55.4	32.9	34.6	20.2	22.5
$\bar{X}$	30.3	32.9	63.2	33.9	32.7	19.4	23.8
S.D.	5.4	4.1	9.2	6.0	6.9	3.6	8.6
MALES							
K	68.6	63.6	132.2	75.0	62.5	48.4	57.5
L	51.5	59.1	110.6	62.2	49.05	36.35	47.0
M	51.1	47.9	99.0	50.4	49.3	29.75	38.6
N	43.0	39.4	82.4	58.6	51.1	40.55	54.05
O	53.6	55.6	109.2	64.0	57.95	48.85	46.35
P	56.0	54.6	110.6	70.9	62.25	28.15	54.75
Q	44.8	52.9	97.7	58.1	49.05	32.7	39.75
R	37.3	41.8	79.1	57.2	50.45	33.6	42.25
S	64.0	56.3	120.3	50.0	48.4	29.3	42.95
T	46.8	47.2	94.0	54.5	47.25	31.35	38.85
$\bar{X}$	51.6	51.8	103.5	60.1	52.72	35.9	66.2
S.D.	9.5	7.6	16.4	8.1	5.8	7.6	7.0

LGS = Left hand grip-strength.

RGS = Right hand grip-strength.

CGS = Combined (L + R) grip-strength.

take into account all the factors which contribute to performance. Thus, skin friction and the elastic resistance of the connective tissue of the hand were not taken into account. More important, however, was the fact that the instrument used to measure hand-grip strength (Takai digital dynamometer) measured isotonic contractile grip-strength, while loading under the conditions of the present experiment provided predominantly eccentric stress on the hand flexors. The cost of eccentric work is less, and the electromyographic (EMG) activity is far lower for the concentric equivalent (Åstrand and Rodahl, 1977). The fact that concentric hand-grip strength values were exceeded is an indirect measure of the subjects' willingness to reach AML carry levels. Both male and female hand-grip values are typical of other population groups of similar age and health status, being of the order of 50 kgf for males and 30 kgf for females (see Figure 3 and Table III).

ABSOLUTE MASS CARRIED

Incremented loads as well as carriage methods resulted in essentially the same response trends for both sexes. The four carrying methods were significantly different from one another, in that load masses carried by both sexes could be distinctly associated with a particular method. This observation confirms the author's proposition that these four manual load carriage methods were indeed different.

For the preferred load condition of all methods, males selected significantly heavier loads than females (see Figure 4). All incremented loads above the preferred values for both sexes were significantly different by virtue of the nature of the load increasing protocol. However, the gradient at which the increments increased in absolute terms was different for males and females: the males chose a steeper incremental gradient (0.37) than the females (0.18).

In absolute terms, at the preferred load (P) level, females carried 65% of the load of males and at the P75 load only 58%. These findings indicate that males show relative increases in functional strength as load increases, and these functional differences were particularly close to the functional differences seen in hand-grip values (see Table II). It is worthwhile to note the order in which methods are related to the magnitude of the load carried as this may be of interest to those involved in MMH activities. These methods involved increases in the following order: Uni x: males = 38.9 kg, females = 23.79 kg; Flx x: males = 49.5 kg, females = 28.79 kg; Ext x: males = 61.79 kg, females = 34.46 kg; Bi x: males = 70.39 kg, females = 45.54 kg.

LOADS CARRIED (PERCENT BODY MASS)

The trends seen when loads were expressed as a percentage of body mass did not differ from those recorded for absolute mass. The four carriage methods were all significantly different from one another, as were the load increments. This was true for both sexes.

Males carried significantly heavier loads (when expressed as a percentage of body mass) across methods as well as for load increments, except in the case of the preferred loads selected for the lateral load carriage methods.

The preferred loads chosen by the females were 81.7% of corresponding male values, but at the P75 level had dropped to only 71.5%. The gradient for load increase of the males was 0.51, while that of the females was 0.30. It must be remembered that by virtue of the fact that the range of masses between MAL and AML was so much greater in the males than the females, the incrementing protocol (Px = MAL + (AML - MAL).x) yielded a steeper incremental gradient for the loading conditions of males (see Figure 5). It is clear that, in absolute as well as relative terms, it is possible to load male subjects with greater incremental masses than females, implying that males can accommodate changes in mass more easily than females.

INCREMENTED LOADS AS A PERCENTAGE OF MAL

When loads were expressed as a percentage of MAL values only one significant comparison was seen, that being between the unimanual and flexed frontal carriage for males. All other comparisons for both sexes proved non-significant. Apart from this comparison, the choice of percentage increments of MAL were similar across the methods for both sexes. However, the males chose, on average for each method, consistently higher percentages of MAL. Unlike the trends recorded for absolute masses carried and masses expressed relative to body mass, the patterning of loads based on MALs did not follow the same order as the two previous methods of expressing load.

For the four load conditions significant differences were seen between all conditions and for both sexes. Although both sexes began at the preferred load value of 100% of MAL, the male values (as a percentage of MAL) increased at a faster rate than did the female values. This trend was caused by the fact that a greater range existed between MAL and AML values for the males than for the females. The percentage increase between load conditions for the males was approximately 30%, while that of females was 20%.

In summary, males chose greater absolute masses, masses relative to body mass and also masses based on percentages of MALs than the females. These relationships are depicted in Figure 6.

ALLOMETRIC CORRECTION FOR DIFFERENCES IN MALE-FEMALE STRENGTH

Basic allometric laws governing the properties of geometrically similar objects differing in size dictate that scaling factors (the ratio L, of corresponding lengths in differently sized objects) increment as the square for areas and the cube for volumes, weights or masses. Strength is proportional to the cross-sectional area (L^2) of muscles and mass is proportional to the volume (L^3). Thus strength, per unit body mass, of a bigger animal (B) has the following relationship to that of a smaller version (S):

$$\text{Relative strength of B} = \frac{L^2 \text{ (strength of S)}}{L^3 \text{ (mass of S)}}$$

$$\text{Allometric correction} = \frac{1}{L} \text{ (relative strength of S)}$$

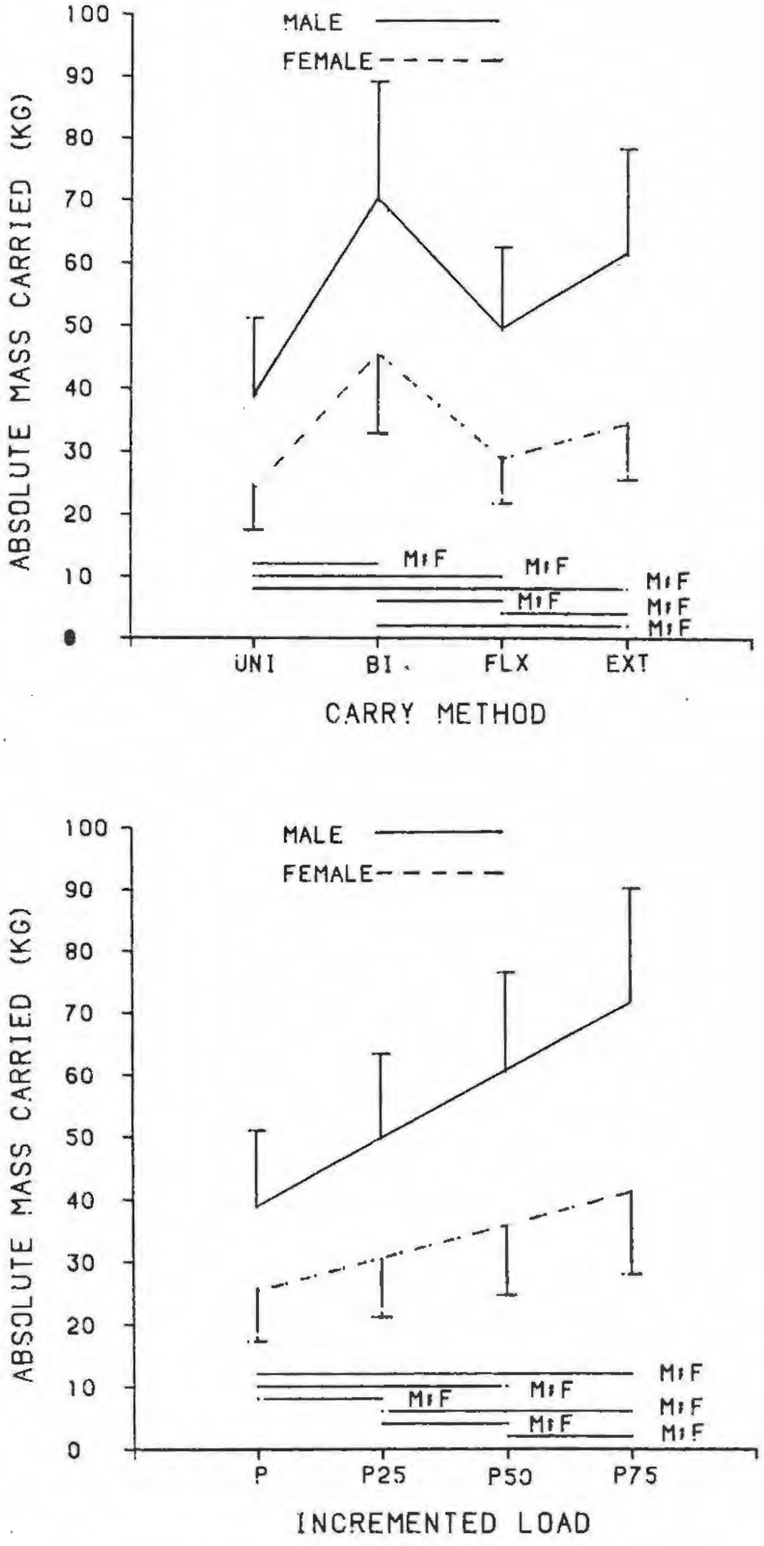


Figure 4: Absolute mass of the preferred and incremented loads.

For the above, and all subsequent graphics, significant differences are depicted in the following manner:

———F = Significantly different female conditions
———M = Significantly different male conditions
———M:F = Significantly different male and female conditions

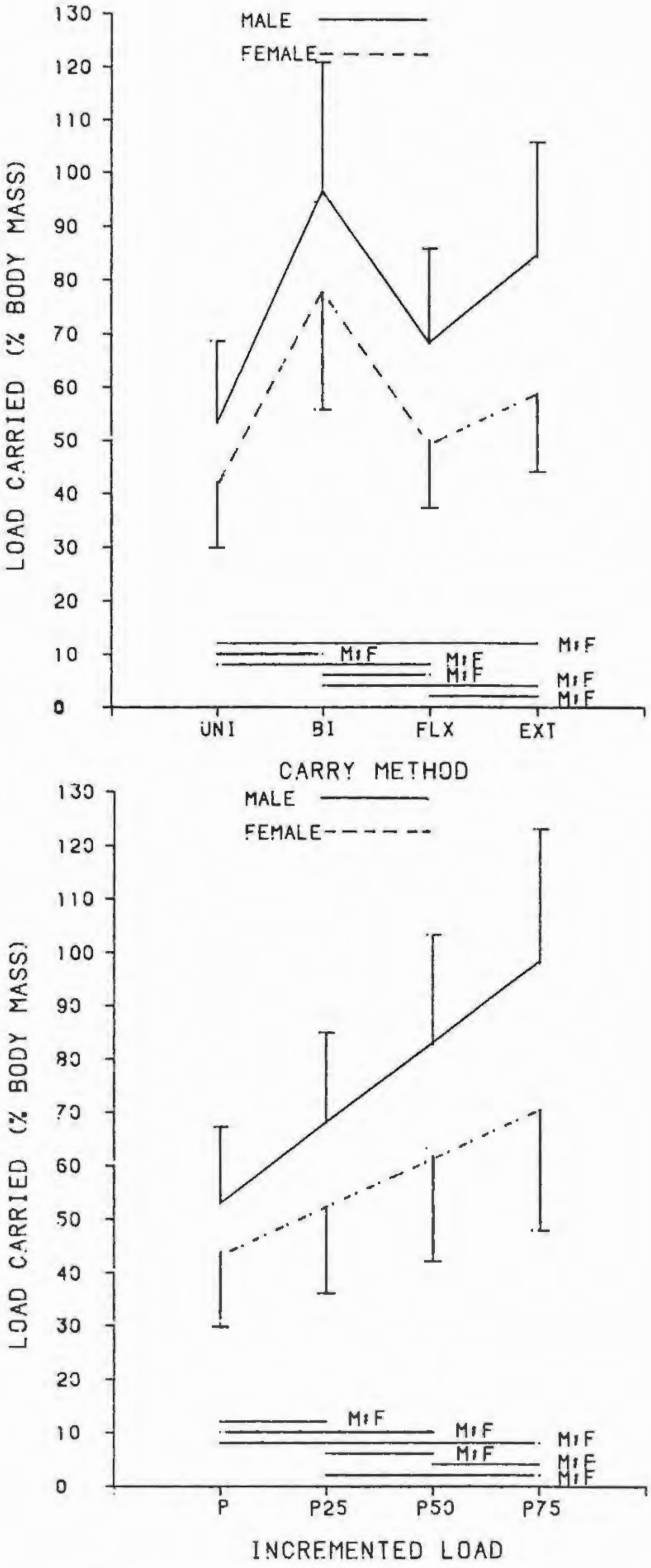


Figure 5: Incremented loads expressed in percent body mass.

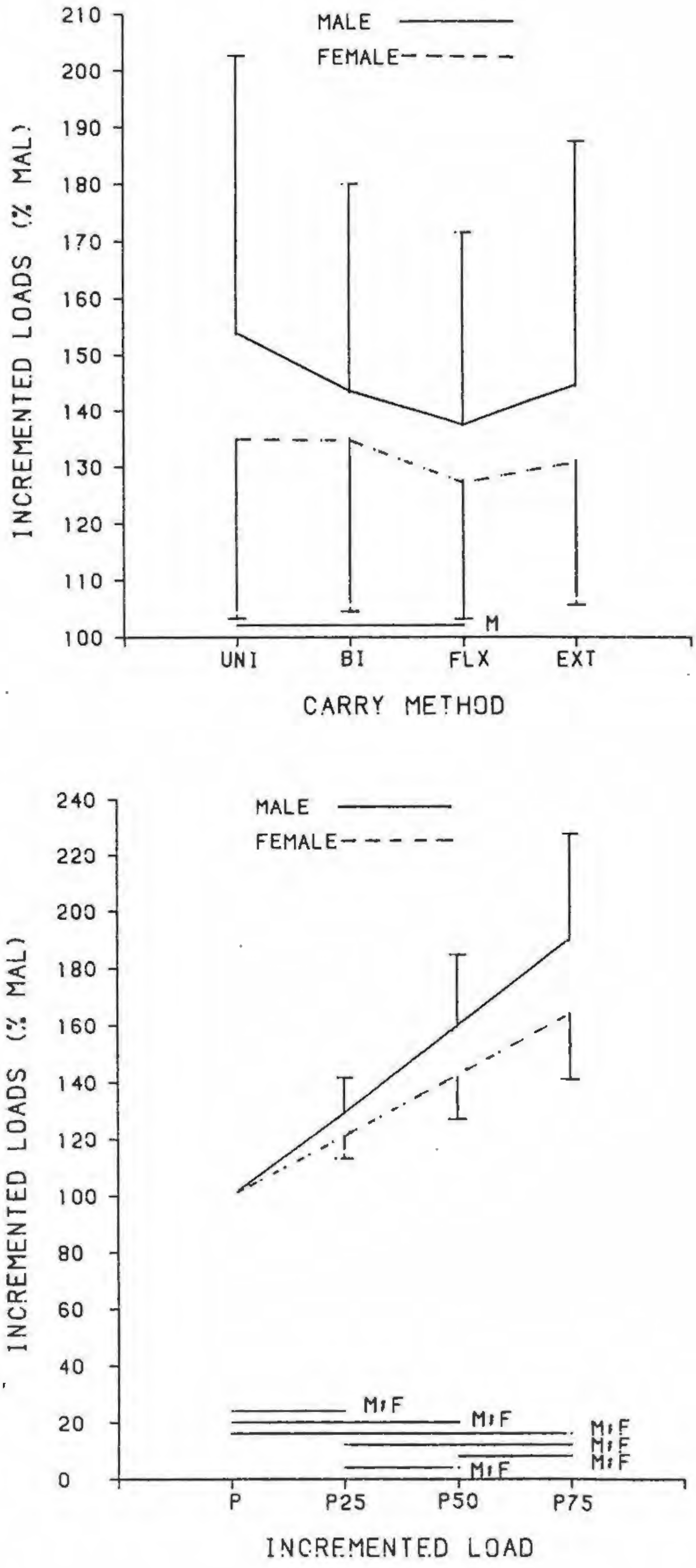


Figure 6: Incremented loads expressed as a percentage of maximal acceptable loads.

Where L = the sex-based ratio of B to S (in stature).

From the above correction for size, and using data collected in the present study, Table IV illustrates the magnitude of male size and strength dominance.

Table IV: Allometric corrections for sex-based strength differences.

	MALE	FEMALE
Stature (cm)	176.8	166.2
Mass (kg)	72.9	58.8
Hand-grip strength (kg)	51.8	32.9
Strength per unit body mass	0.710	0.559

Measured strength difference per unit body mass = 78.7%.

On allometric correction for stature (female : male), female size-corrected strength = $\frac{1}{1.063}$ (0.559) = 0.525 kg.kgBM^{-1}.

Actual measured male relative strength = 0.710 kg.kgBM^{-1}.

Therefore, female size-corrected strength = 73.9% of the males'.

Although it appears that females are relatively weaker than males even when size-corrected for measured strength (grip-strength) and carrying performance (AML), it is prudent to note the following:

1. The greater overall percentage lean body mass of males.

2. The disproportionate muscle distribution in the upper body of males.

3. The greater lifting experience of males.

According to Wells and Plowman (1983), the mean fat percentages of male and female adults are 14% and 24% respectively.

Using allometrically corrected values for upper body size (biacromial width) , as well as masses adjusted for lean body mass, the adjusted grip strengths of males and females may be derived in step-wise fashion as follows:

Table V: Size and body composition sex-based strength differences.

	Males	Females	Size correction factor	Percentage females of males
Biacromial width (cm)	40.1	36.1	0.94 *	86.4
Body mass (kg)	72.9	58.8	-	80.66
Body fat (%)	14	24	-	146.6
Size-corrected grip-strength (kg)	51.8	30.92	0.94	63.51
Lean body mass (LBM) (kg)	62.69	44.68	-	73.9
Size-corrected strength per unit LBM (kg.kgBM^{-1})	0.826	0.692	-	80.6
Size and width corrected strength per unit LBM (kg.kgBM^{-1}.cm^{-1})	0.826	0.80	1.157 #	96.8

* female stature corrected to male stature.

\# male/female biacromial width differences following size-correction.

Having corrected for size, lean body mass and muscle distribution, female grip-strength values equalled 96.8% of the male scores. The remaining small (3.2%) disparity may well be accounted for by the following:

1. Subject motivation and relative competitiveness.
2. Subjects' experience in recruiting maximal voluntary contractions under similar conditions.

WALKING VELOCITY UNDER PREFERRED SPEED (FREE CHOICE) CONDITIONS.

When the absolute velocities of all 17 conditions (one unloaded and 16 loaded) were subjected to a sex-based comparison the males clearly walked marginally faster than the females (1.22 $m.s^{-1}$ versus 1.15 $m.s^{-1}$). Although these differences were statistically significant they were not of practical consequence under the conditions of this experiment, for reasons that require explanation.

Firstly, the absolute difference of 0.07 $m.s^{-1}$ between the mean speeds of males and females would allow two individual walkers traversing 10 m at these speeds to be within arms reach of one another, and who might, therefore, without hinderance, have carried an object of 60 cm long between them. Secondly, the mean cadence differences between the sexes, when reduced to the times taken to traverse the 10 m walk zone, amounted to less than one step per minute, and finally, the stride length difference between the sexes, in percent of the 10 m walk, was only 0.2%.

With the knowledge that absolute velocity is the product of step length and cadence, and having demonstrated that these practical differences between males and females were very small, the velocities resulting from the two products in practical terms were deemed to be identical.

UNLOADED GAIT KINEMATICS VERSUS THE INCREMENTED LOADS ACROSS THE CARRIAGE METHODS

The males in this study were significantly larger and stronger than the females. However, the preferred velocities chosen by both sexes for the loaded conditions did not differ significantly from the unloaded walk. Males did walk at significantly faster speeds across all conditions than females, although these speeds, relativised for stature, showed that no significant differences existed between the unloaded and the loaded conditions or between the sexes (male x = 0.691 statures.s^{-1}; female x = 0.694 statures.s^{-1}).

Although subjects chose to maintain similar walking speeds across all conditions, both incremented load and carrying method had significant effects on the constituent kinematics. The temporal (stride time) and distance (stride length) factors, as well as cadence, were all subject to change under load increases or differing carrying methods. Increasing load reduced stride time and stride length while causing an increase in cadence. Cadence increases were of such a magnitude as to negate the speed-reducing effects of decreasing stride length, thus allowing for the maintenance of similar velocities (see Table VI). In summary, as load increased, more significant foot-floor kinematic differences were found between the values for unloaded walking and the load carrying conditions, particularly at the P50 and P75 levels.

Different methods of load carriage also elicited significant differences in the kinematics associated with velocity. Under virtually all load conditions in the frontal carriage methods, significant differences were observed when compared against the unloaded condition. These two load carriage methods have a tendency to reduce lower limb excursions and thus modify stride lengths. The lateral load carriage methods did not impede lower limb excursion to the same extent. However, as loads became heavier (P50, P75) a greater number of parameters were affected. In summary, the kinematics associated with velocity were disturbed more readily by frontal carriage methods than by lateral carriage methods.

For the support-to-swing ratio, total support and double support few differences existed between the unloaded and loaded walking conditions. Although loads appeared to increase the values of the parameters under discussion, rarely were these values large enough to produce significance. It is interesting to note that the greatest number of significant differences was seen in the lateral carriage methods. Under the bimanual conditions the heaviest absolute loads were carried. Extrapolation to values in excess of those considered in the present study may result in a greater number of significant differences being

Table VI: Significant effects of load and of carriage method on selected kinematic parameters of normal unloaded locomotion at the same speed.

			UNI				BI				FLX				EXT			
		Normal	P	P25	P50	P75	P	P25	P50	P75	P	P25	P50	P75	P	P25	P50	P75
Stride Length	F	128	118.8	118.9	116.4*	114.7*	123.2	120.8	120.9	117.4	111.1*	113.5*	109.9*	111.9*	104.3*	103.3*	101*	99.1*
	M	128.4	126.4	123.3	121.5	114.1*	124.7	125.5	124.2	121.1	117.4*	113.6*	112.9*	108.5*	105.8*	103.2*	100.1*	92.3*
Stride Time	F	1.1	1.056	1.058	1.027	0.965*	1.024	1.022*	0.999*	0.968*	0.966*	0.964*	0.93*	0.932*	0.98*	0.963*	0.974*	0.947*
	M	1.088	1.029	1.016	0.98*	0.897*	1.062	1.012	0.977*	0.924*	0.998	0.948*	0.929*	0.897*	0.93*	0.912*	0.886*	0.854*
Cadence	F	109.1	114.1	113.6	117.2	125.5*	117.3	117.7*	120.4*	124.5*	124.6*	124.2*	129.2*	128.8*	122.5*	124.5*	123.6*	126.9*
	M	110.6	117.3	119.2	124.7*	136.3*	114.1	119.8	125.2*	131.9*	122.4*	128.3*	131.8*	136.8*	130.9*	133.2*	137.2*	142.2*
Velocity	F	1.169	1.136	1.134	1.147	1.207	1.212	1.192	1.221	1.225	1.157	1.187	1.193	1.208	1.073	1.082	1.045*	1.053
	M	1.201	1.256	1.244	1.281	1.313	1.206	1.275	1.309	1.35	1.221	1.15	1.253	1.241	1.172	1.158	1.156	1.1
S-S Ratio	F	1.67	1.833	2.058	1.859	2.161	1.913	1.881	1.95	1.902	1.886	1.747	1.807	1.782	1.738	1.749	1.852	1.908
	M	1.748	1.779	1.802	1.904	2.07*	1.92*	1.898	1.97*	1.949	1.778	1.804	1.826	1.911	1.844	1.794	1.813	2.04
Total Support	F	62.5	64.6	66.1	64.9	67.1	65.2	66.5	65.8	65.5	65.1	63.5	64.3	63.9	63.5	63.6	64.7	65.5
	M	63.6	64	64.3	65.5	67*	65.7*	65.4	66.2*	66	64	64.3	64.5	65.6	64.6	64	64.3	66.8*
Double Support	F	27	28.45	28.83	28.46	31.88	28.34	29.15	29.76	29.48	28.22	27.21	28.42	27.14	24.98	26.31	27.33	30.02
	M	26.07	25.98	26.58	27.79	31.51*	30.2*	29.94	29.54	30.74	26.85	28.01	30.55	30.5	25.98	27.15	27.02	31.43*
Relative Speed	F	0.705	0.684	0.681	0.69	0.727	0.73	0.717	0.734	0.738	0.696	0.714	0.716	0.728	0.646	0.651	0.628*	0.635
	M	0.678	0.707	0.702	0.723	0.741	0.681	0.719	0.74	0.745	0.688	0.694	0.708	0.701	0.661	0.654	0.653	0.622

* Value is significantly different from the value obtained from unloaded gait.

seen, but this is conjectural. Finally, it is worth noting that the gait pattern is highly resistant to changes, even when awkward, heavy loads are carried. Although there might be an initial displacement of load values from unloaded values (for example in the support-to-swing ratio), the rate of further displacement away from normal values is slow and unlikely to produce significant differences until extreme loads are carried (see Table VI).

THE EFFECTS OF METHOD AND LOAD ON SELECTED GAIT KINEMATICS

Absolute Velocity

Under all experimental conditions the males, being larger, walked at speeds that were marginally faster than the females. For both sexes the lateral bimanual carrying method elicited the fastest velocity. There was a significant difference between this method and the frontal extended carry in both groups and the males also exhibited a significant difference between the lateral unimanual and the frontal extended carriage methods (Figure 7).

Both frontal carriage methods could potentially impede the lower sagittal excursions of the lower extremities and as a consequence, reduce the load bearing velocity. Increasing load, however, did not affect velocity significantly. Extrapolating the load trend, it is possible that further increases might have driven a significant increase in velocity, perhaps indicating that subjects might want to complete the task as fast as possible for reasons probably unrelated to gait (perceived exertion, for example). This, however, is purely conjectural.

Relative Velocity

Males, being larger, walked faster than females in all conditions. However, when these differences, marginal in extent (1.22 $m.s^{-1}$ for males; 1.15 $m.s^{-1}$ for females), though statistically significant, were normalised for stature, they disappeared, there being no difference in the relative speeds (x = 0.07 $statures.s^{-1}$) of the two sexes in any condition. The relative speeds of both sexes were significantly influenced by portage method. Among the males the extended frontal carrying method was significantly slower than all the other methods. The females showed significant differences between the extended frontal carrying method and the two lateral carriage methods, and also the flexed frontal carriage method (Figure 8).

The extended frontal method appears to reduce load carrying speed, most probably by impeding lower extremity ranges. Load increments, however, did not exert a significant influence upon relative speed.

The Preferred Speed Protocol

The males were significantly taller than the females, and stature is known to exert a significant influence on kinematic parameters such as temporal (cadence), distance (stride length) and angular excursion (inter-segment angles) factors (Grieve and Gear, 1966). It is a major finding of this study, and probably not coincidence, that under a freedom-to-choose protocol, the two sexes opted for stature-normalised portage speeds which were not different statistically. Furthermore, in absolute terms, none of the speeds chosen by both sexes under loaded conditions differed significantly from the speeds chosen under the unloaded condition. What this means is that it was possible in the analysis of data to proceed as if speed had been controlled, and held constant between the sexes.

Of great interest and analytic convenience was the fact that load increments did not have significant effects on walking speed, and the "baseline" condition (normal walk at preferred speed, unconstrained by load) was likewise, performed at a speed not significantly different between the sexes, or from those used in any of the experimental (load carrying) conditions. In short, throughout this study the subjects chose to walk at, on average, 0.7 statures.s^{-1} relative speed.

Cadence.

Cadence appears sensitive to different load carriage methods, as well as to increasing load, in both males and females. Stepping rate was higher in the males than the females by virtue of their faster absolute walking speeds. In both sexes the load-driven cadence increases were overall effects: the P25 load increment showed no change over preferred load, but in both sexes there was a significant cadence increase between P25 and P75 (Figure 9).

Among the females the lateral carrying methods (uni. and bi.) were significantly different from the frontal (flx. and ext.) methods. Furthermore, a significant difference was seen between the bimanual lateral and the flexed frontal carriage method. It would appear that, in general, pendant lateral carriage methods differed from bimanual supported carriage in front of the body. This trend was less obvious among the males, whose lateral carriage methods differed only from the frontal extended carry.

The frontal (flx.) carrying method did not appear to affect cadence to the same extent in the males as in the females, a finding which might be attributed to the greater upper limb strength of the males, who were able to maintain the position more easily, with less interference from lower limb excursions.

Significant increases in load, and the imposition of awkward load-carriage methods (particularly if they limit the sagittal excursions of the lower extremities) appear to elicit increases in cadence under speed-constant conditions. Since even without load increments, cadence increments significantly increase the oxygen comsumption of locomotion, this is a finding of considerable importance in the field of manual materials handling (MMH).

Stride Length

Stride length responses of the males and females were very similar. While the lateral carriage methods (uni. and bi.) were not significantly different, all other method combinations were. The bimanual lateral load carriage method apparently allowed a greater freedom of limb movement than the unimanual lateral method, which, by restricting the movement of the limb on the loaded side, had thus an effect on both sides. The lateral carriage methods clearly permitted greater stride lengths than the frontal methods (Figure 10). The latter two methods were observed to exert influence in postural (trunk) inclination, in addition to restricting lower extremity range of motion (see Figure 1 and 2).

In females, increasing load did not appear to influence stride length significantly. The pattern in the males, however, was more marked and showed a significant decrease in stride length between the lightest (P and P25) and the heaviest (P75). This sex-based difference may have its origin in the fact that when expressed as a percentage of body mass, the loads carried by the females were significantly lighter than those carried by the males and as a consequence may not have been sufficient to bring about a significant reduction in the stride length. It should be noted that speed was not specifically controlled. Nevertheless, it did not vary significantly across the conditions or between the sexes and was, to all intents and purposes, fixed. It follows, therefore, that the general tendency for cadence to increase with load or awkwardness of carrying method, should be mirrored by a step length (and hence stride length) decrease. This was, in fact, what was found.

Stride Time.

For all carrying methods, as well as all incremented loads, males displayed a lesser stride time than females (Figure 11) The females showed no difference between the two frontal methods of carriage, or between the lateral methods, in terms of stride time. This bears out the findings for both absolute and relative velocities, and is further reinforced by the females' cadence results. However, each lateral carrying method differed significantly from one or both of the frontal carrying methods. The male stride time trends were broadly similar.

Increasing loads had the effect of reducing stride time for both sexes. However, the males had consistently shorter stride times than the females and tended to respond more sensitively to load increments due to disproportionately heavier preferred loads, as discussed elsewhere.

Support-to-Swing Ratio.

The support-to-swing ratio was not significantly altered either by increasing load or by different carrying methods. There was no sex-based difference, and variability (as expressed by standard deviation bands) was large (Figure 12).

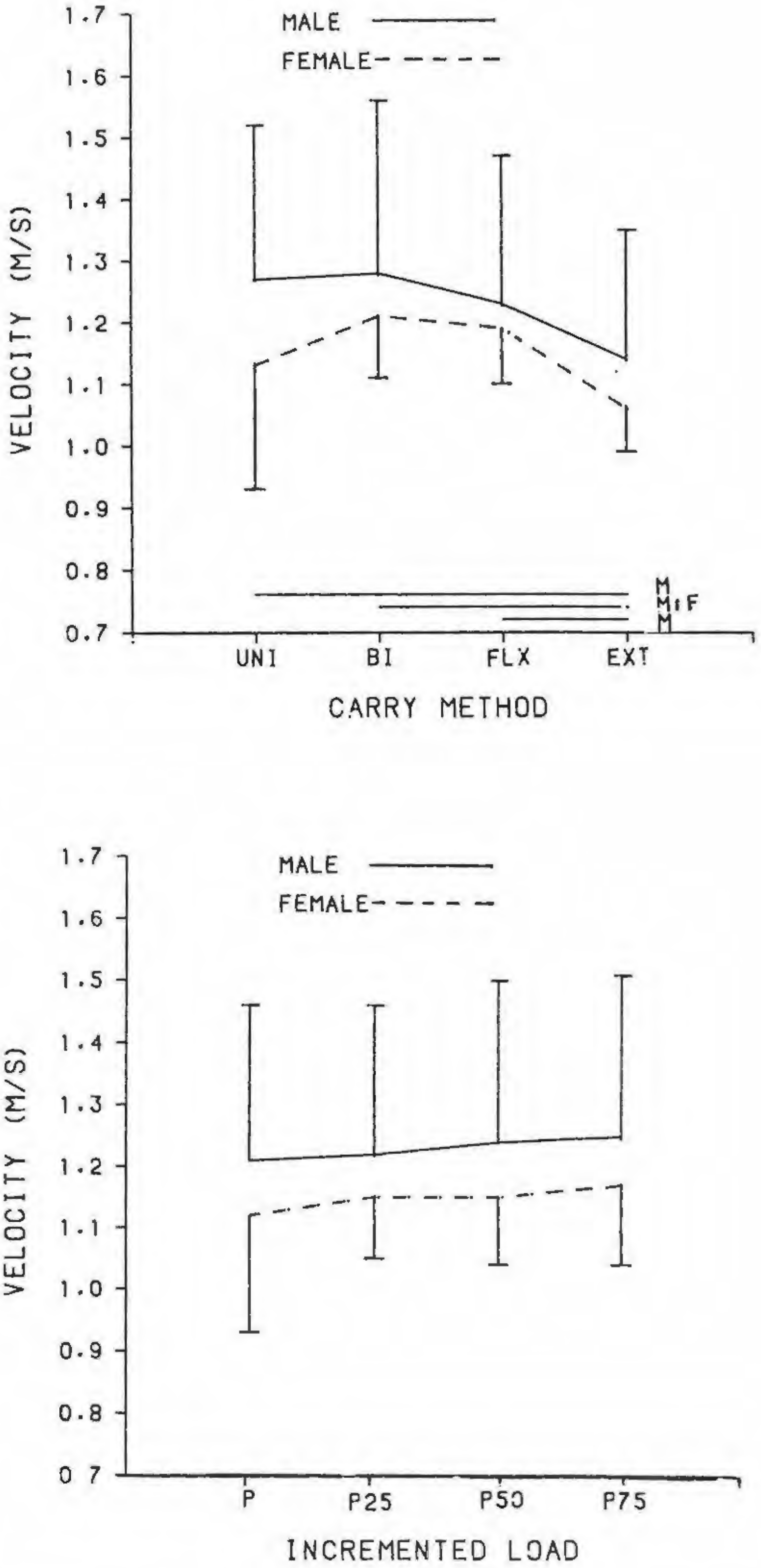


Figure 7: Effects of load and of carrying method on absolute velocity.

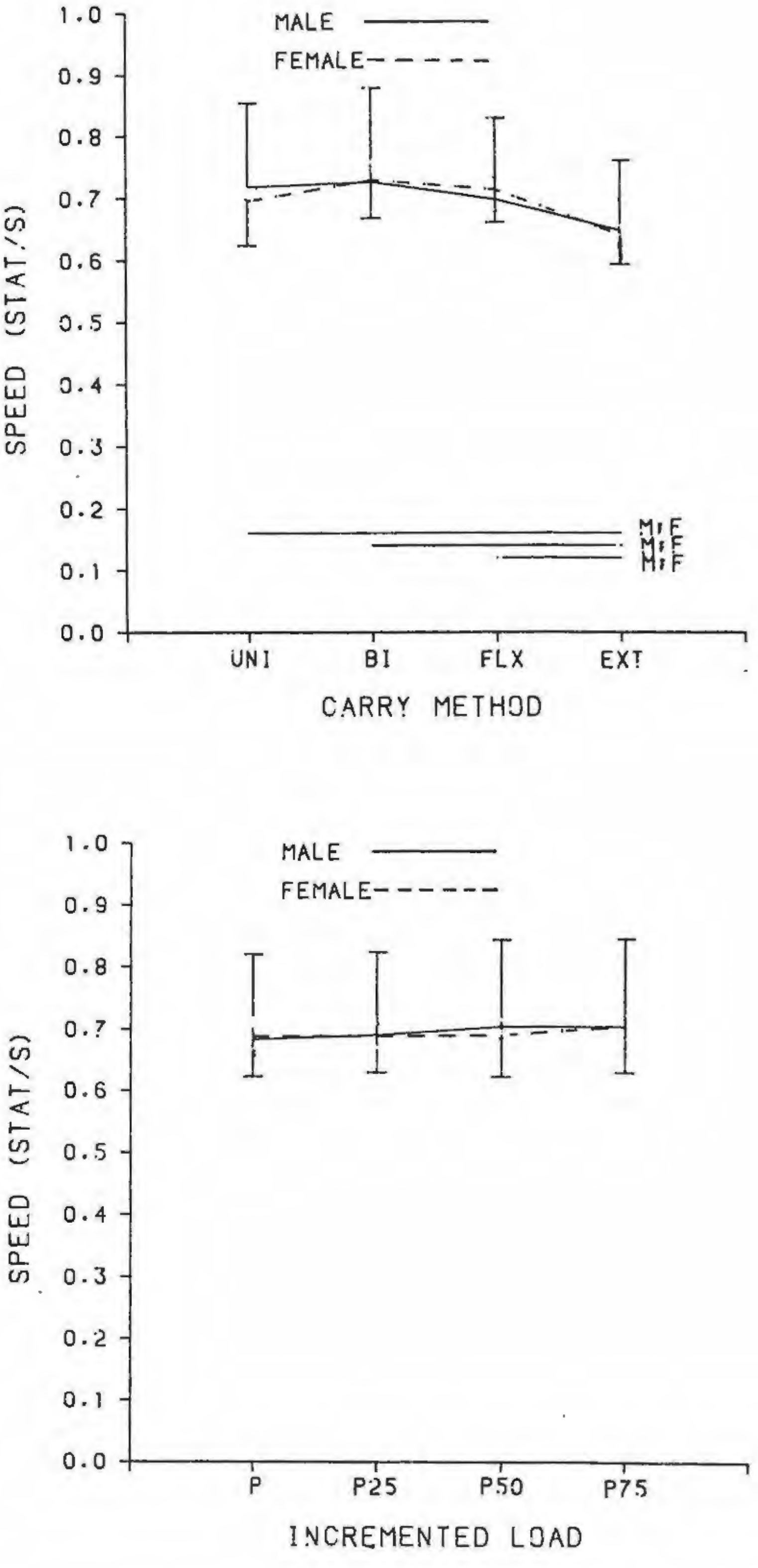


Figure 8: Relative velocity: Effects of load and of carrying method.

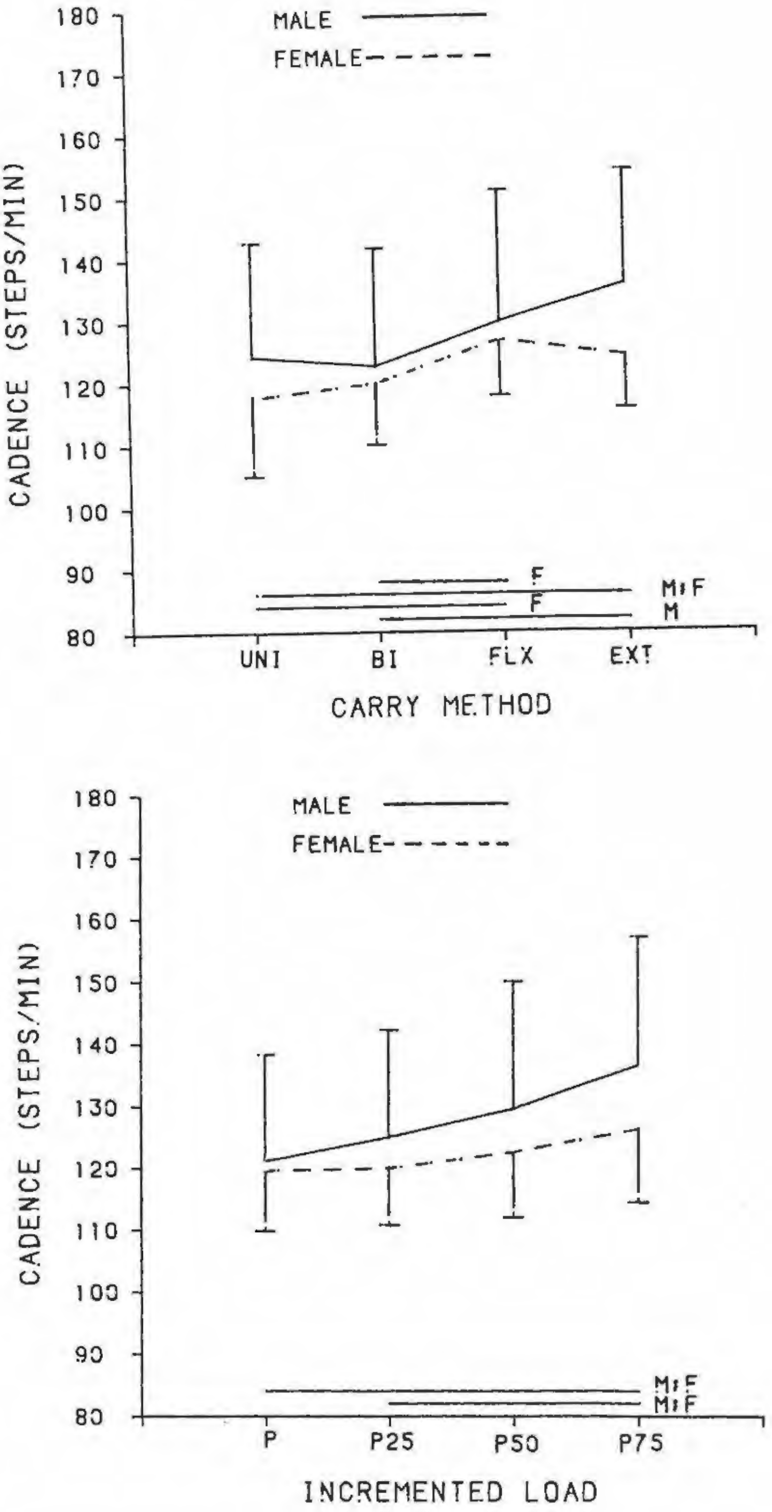


Figure 9: Effects of load and of carrying method on cadence.

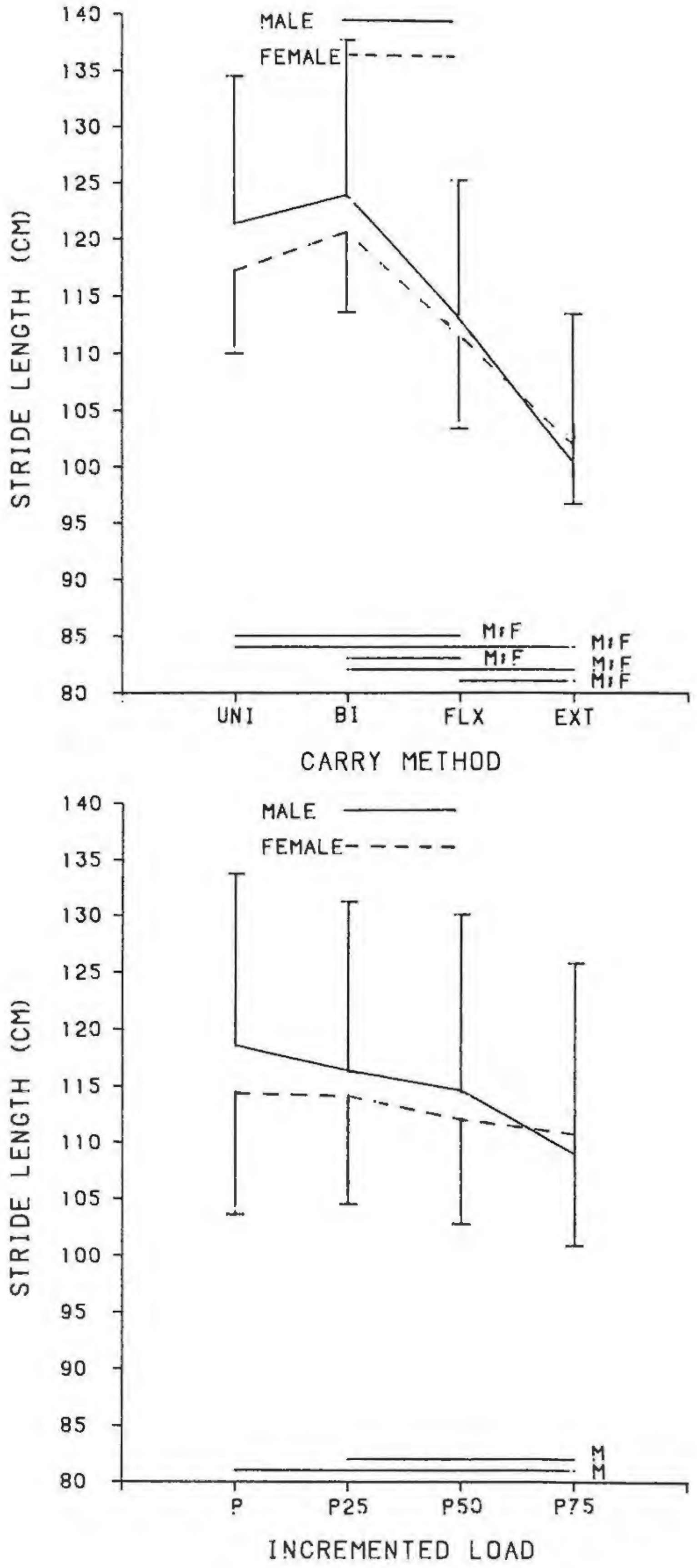


Figure 10: Effects of load and of carrying method on stride length.

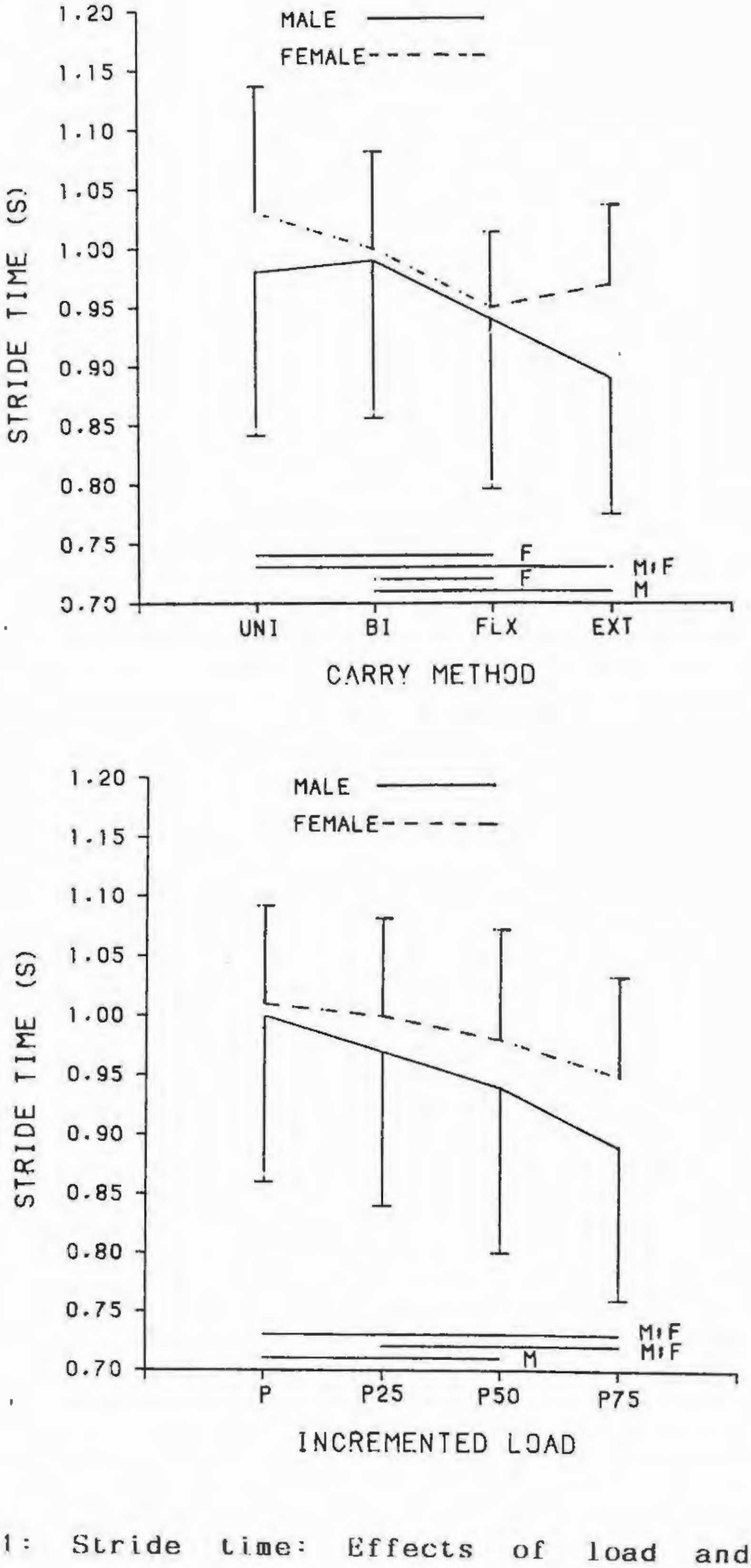


Figure 11: Stride time: Effects of load and carrying method.

It is concluded that the stride-relative temporal factors for foot-floor contact are remarkably resistent to changes under various loads or carrying methods. What is remarkable, however, is the fact that the basic (speed-related) ratio under normal walking conditions unconstrained by load carriage, is disrupted immediately when any load is carried, regardless of extent or method, and not thereafter altered by the diverse condition changes imposed by this study.

BASIC TEMPORAL PATTERNS OF FOOT-FLOOR CONTACT WITHIN THE STRIDE

Total Support (in Percent of Stride Time)

In general, neither load nor carrying method exerted significant effects on total support when expressed as a percentage of stride time. This was the case for both males and females. However, it can be seen that under both conditions males spent (marginally) relatively more time in support than females. This, in turn, means that males exhibited faster recovery (swing-through) and hence must have spent relatively less time in single support and relatively more time in double support, than the females. These relationships are shown in Figure 13.

In short, carrying methods had no significant effect, for either sex, in altering the percentage of stride time spent in foot-floor contact (overall). The fact that the male values were marginally higher than those of the females suggested the possibility of a larger relative period of double (and hence stable) support. This was to be expected, since the males did carry disproportionately heavier loads than the females. Load incrementation in general had no effect on relative support time, except in comparisons (males only) of the heaviest (P75) against the two lightest (P and P25) loads.

Total Double Support (in Percent of Stride Time)

Study of the effects of carriage methods and of incremented loads upon the percentage of stride time devoted to a stable support on both feet (total double support) revealed virtually no significant differences. The sole exception was between the heaviest (P75) and lightest (P) loads and this was true only of the males. Interestingly, the males did carry absolutely and relatively much heavier loads (by choice) than females. This suggests the possibility that further load increments may have elicited significantly longer double support periods in both sexes, but this is conjecture beyond the data obtained (see Figure 14). In fact, the clear evidence of no significant increases in relative double support time in response to incremented loads, and no significant changes in double support time as a function of various carriage methods, argues against discussing a load-elicited tendency towards an increase with respect to total support time, particularly in the face of little evidence (only males at the heaviest load) of significant differences in total support (see Figure 13).

There were essentially no within-stride relative differences between the sexes or between the loads within the sexes in either total support or double support times, when expressed as a percentage of stride time. It follows that single support (and hence swing) times, relative to stride time, must behave similarly: under the preferred speed and load conditions imposed in this study the patterns of foot-floor contact are not subsequently altered by portage method or load.

This finding is critically important in the practical field of manual materials handling (MMH), where loads are physically transported: it lends support to a reasonable presumption that the relative temporal factors of foot-floor contact are not liable to minor, or even moderate stresses, of awkward carrying posture or inconvenient load.

This finding is strongly reinforced by the complete absence of significant changes (for method, load and sex) in the support-to-swing ratio. This ratio has been widely used by gait analysts because it is extremely sensitive to changes in walking speed (the ratio reduces as speed increases) and because it is highly liable to limp-caused alterations in temporal patterns as measured in clinical situations. A very rough rule of thumb contends that a normal support phase is 60% of stride time (a 60:40 ratio, or 1.5). The ratio varies, roughly from 1.7 at slower speeds to 1.3 at faster speeds in the normal range of speeds adopted by adults in daily living. Figure 12 shows load-elicited ratios between 1.8 and 2.0 at speeds for which, if unconstrained by load, about 1.5 would be expected. Clearly the imposition of any load immediately increases support time in both males and

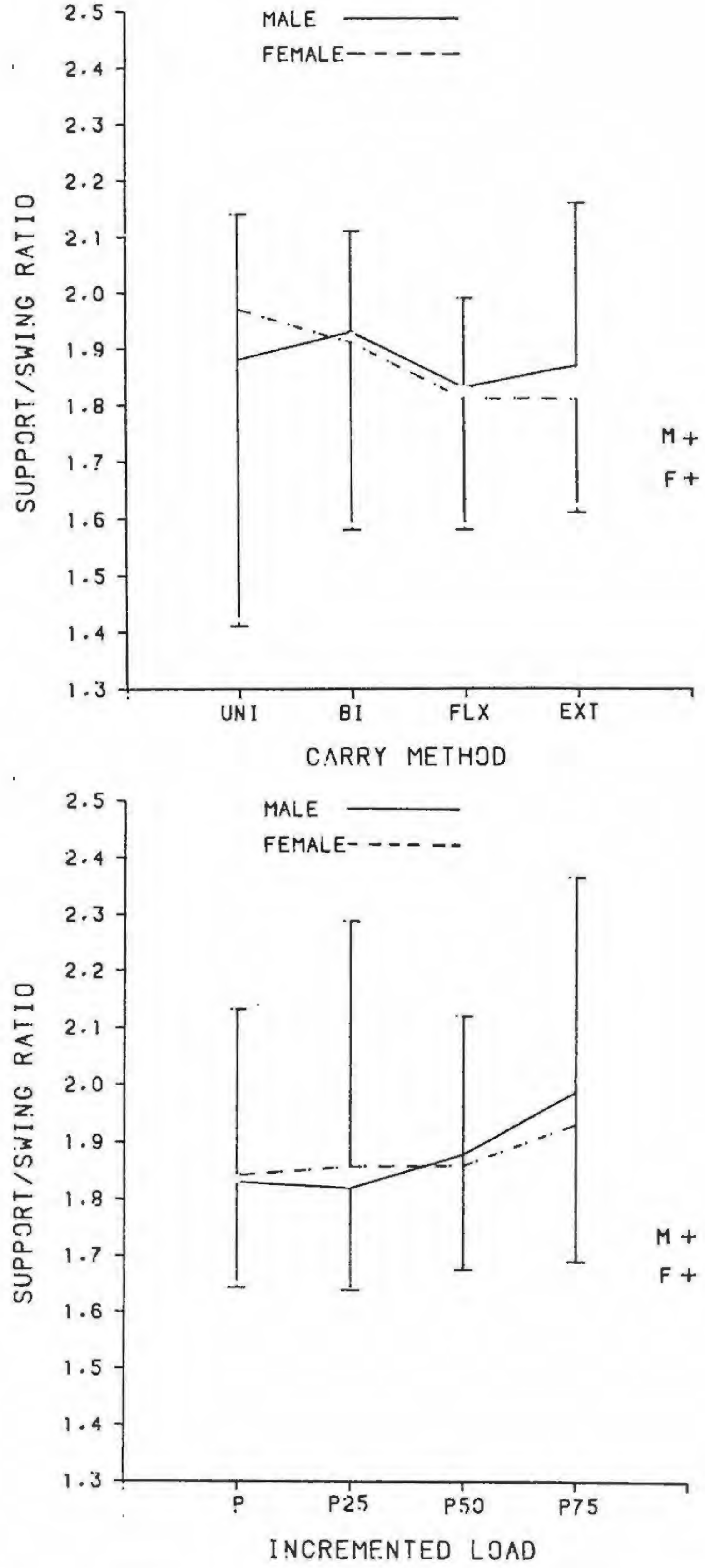


Figure 12: Support-to-swing ratio: Effects of load and of carrying method.

Note: M and F = Unloaded swing-to-support ratio values.

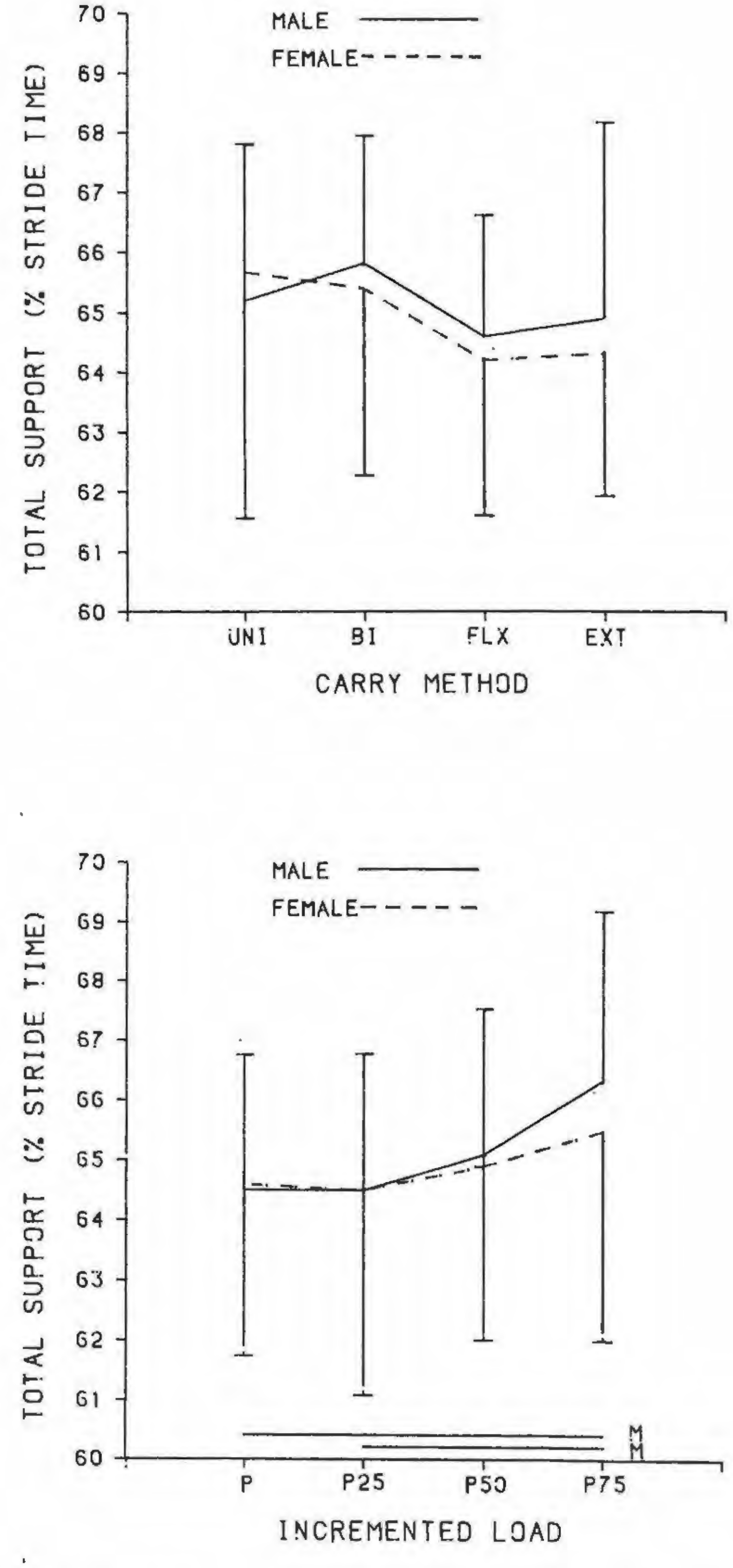
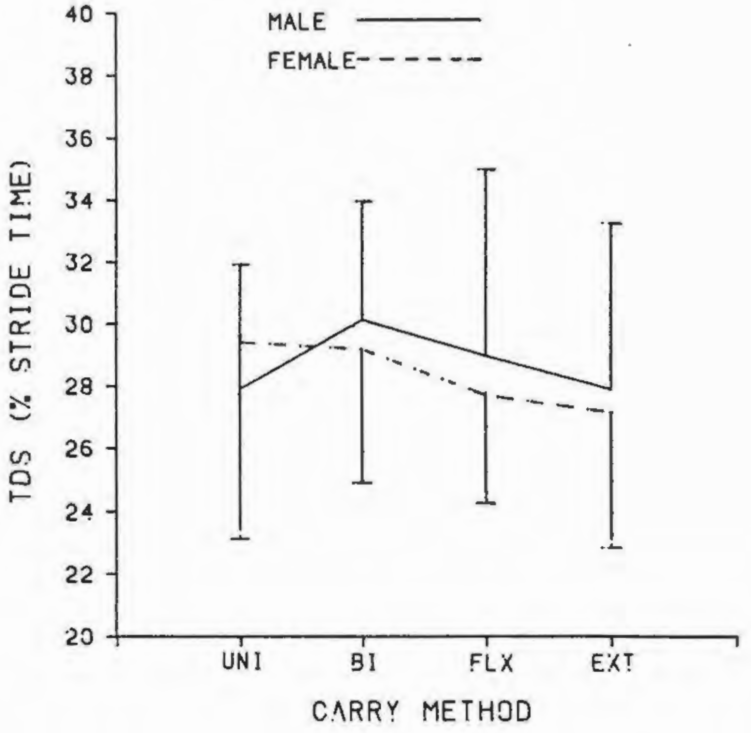


Figure 13: Effects of load and of carrying method on total support (in percent of stride time).



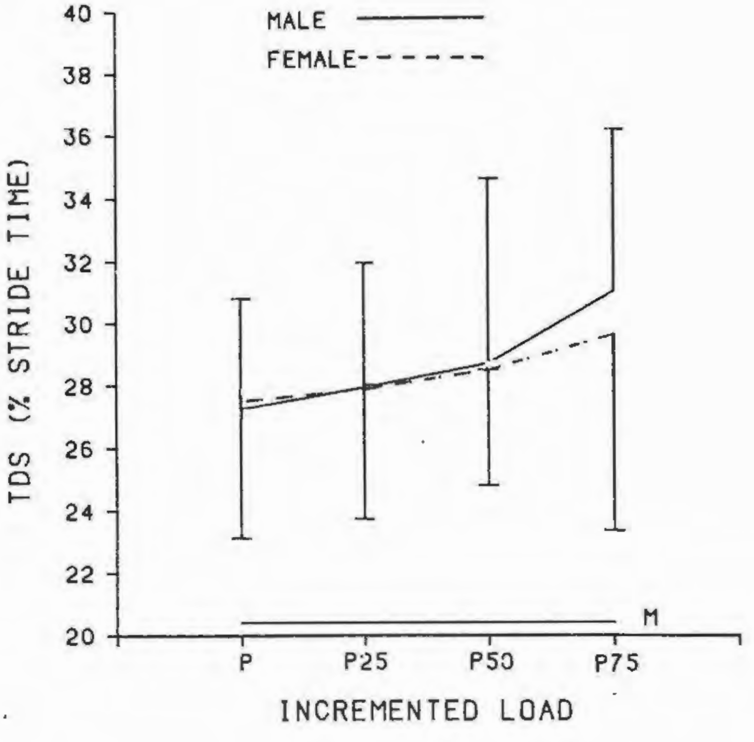


Figure 14: Effects of load and of carrying method on total double support time (in percent of stride time).

females. Moreover, the various portage methods used all pushed the ratio between 1.8 and 1.98, but in highly variable ways from subject to subject, resulting in very large standard deviations.

PSYCHOPHYSICAL RATINGS

RPE Overall.

Overall RPE responses of males and females to the load carriage conditions were very similar, for carrying methods and incremented loads. The different methods did not elicit any significantly different RPE responses between the sexes, the mean response of the males being 12.7 and that of the females, 12.4. These values on the RPE scale correspond to the verbal anchor "somewhat hard" (Figure 15).

Load, however, produced ratings of perceived exertion ranging from a value rated as "very light" for the preferred load, to "hard" for the P75 condition. All four load conditions produced RPE values that were significantly different from one another, indicating that increasing loads were perceived as requiring significantly greater exertion by both males and females.

The perceived exertion rating of 9 ("very light") which was recorded for MAL indicates that subjects were predisposed to selecting loads that were low on exertion. In a study conducted by Snook (1978) on MAL at the 50th percentile for an 8.5 m walk (one carry in eight hours by the flx. method), males chose a mass of 32 kg, and females 22 kg; for the ext.

carrying method males chose 42 kg and females 26 kg. In the present study, MAL values for these two carrying methods were 36.1 kg and 22.8 kg (flx.) for males and females respectively; and 43.5 kg and 26.4 kg (ext.) for males and females respectively. Comparison of these figures reveals that they were in close similarity, suggesting that the subjects of these two studies perceived exertion in a similar way (see Figure 13).

The P75 load elicited an RPE of 15 ("hard"), which was in agreement with the effort required by the incremented load protocol. This rating confirmed in perceptual terms that subjects were not stressed to maximal levels and as such the safety margin required by this study was adhered to. Finally, the ratings strongly indicate that even for short duration work, differing intensities of workload can bring about meaningful ratings of perceived exertion (see Figure 15).

RPE Local.

Ratings of local perceived exertion followed trends similar to those of overall perceived exertion (Figure 16). Again no significant differences were seen due to method. The mean response due to method was a rating of 12.5 for males and 12.2 for females. These scores most closely approached the verbal description "somewhat hard" (13).

For both sexes the MAL (P) load condition was rated at approximately 9 ("very light"), while the heaviest condition (P75) was rated just in excess of 15 ("hard") by both sexes.

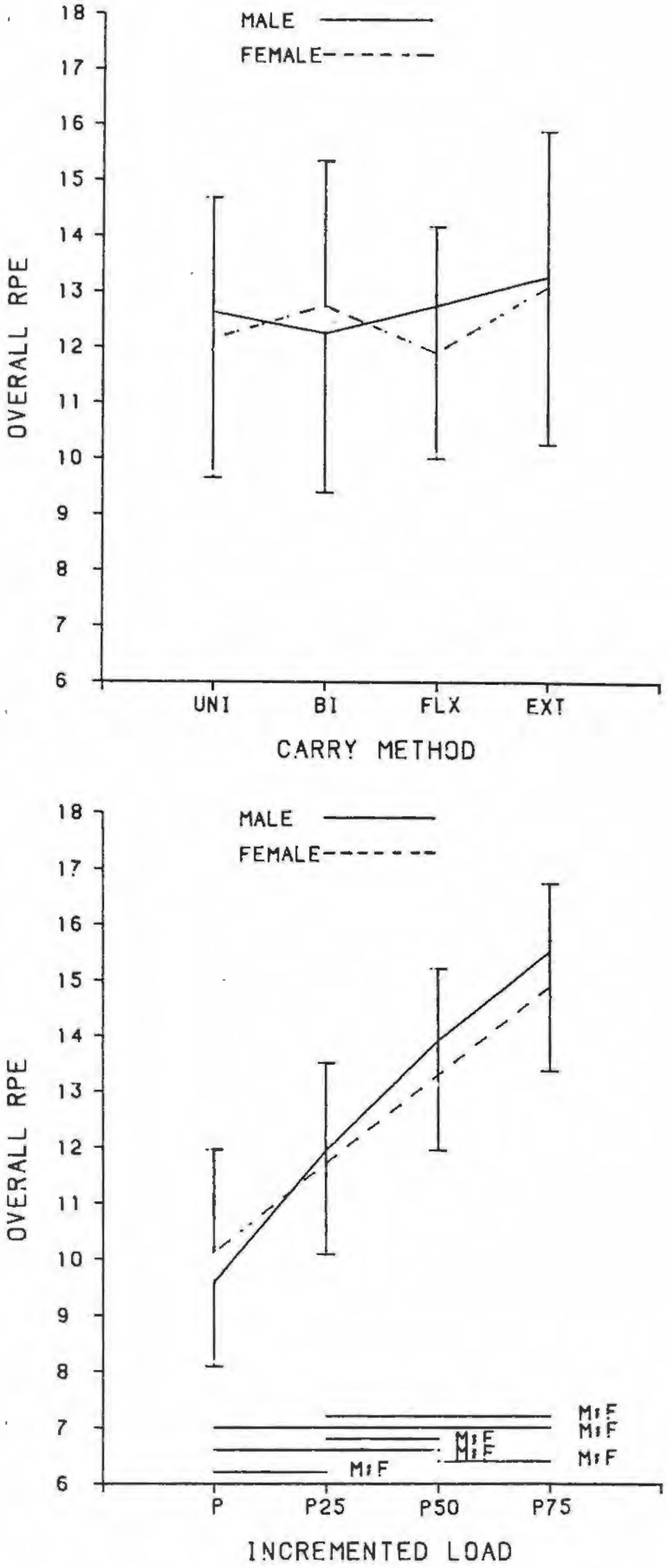


Figure 15: Ratings of overall perceived exertion (RPE): Effects of load and of carrying method.

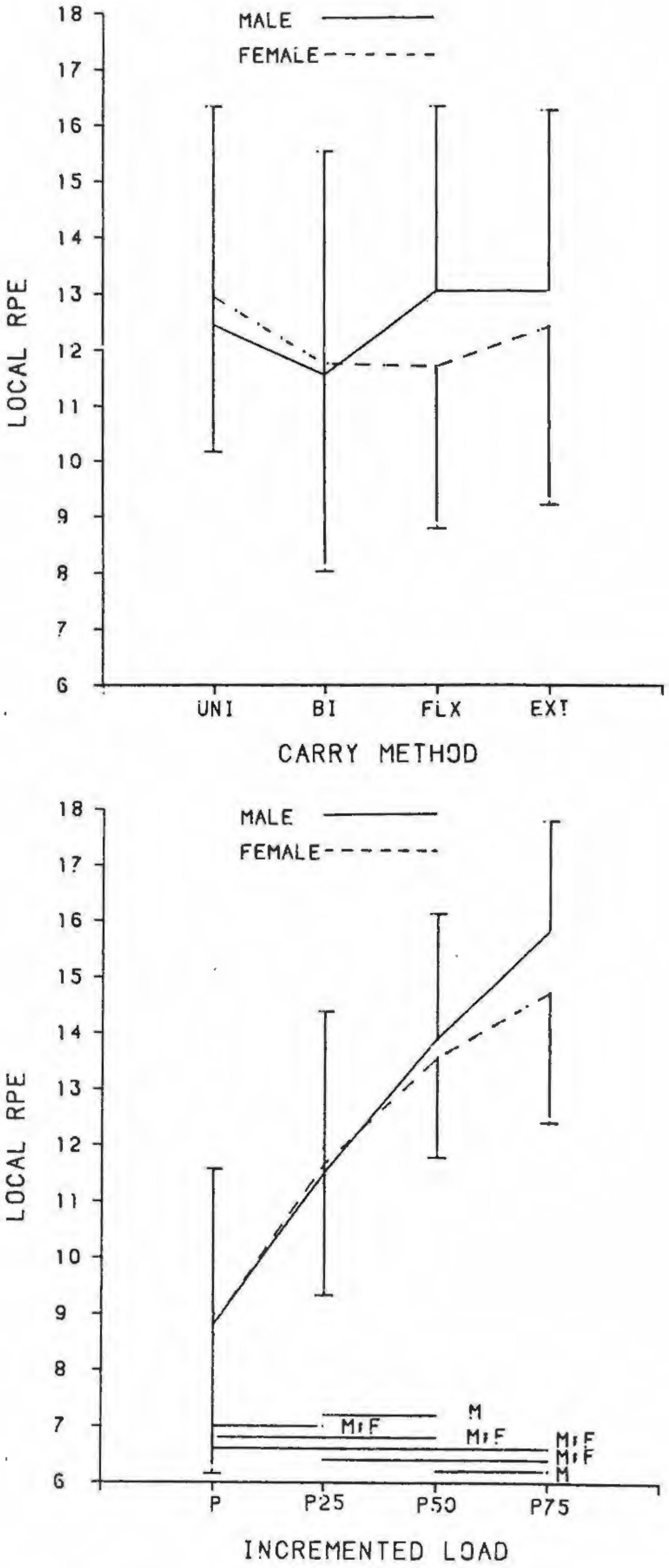


Figure 16: Ratings of local perceived exertion (RPE): Effects of load and of carrying method.

For the females no significant differences in perception of exertion (local) existed between load P25 and P50 and also P50 and P75, although all other load comparisons proved significant. For the males all the RPE scores between each load were found to be significantly different (Figure 16).

Owing to the great similarity between the trends seen in local and overall exertion it might be difficult to ascertain which gives a better indication of the task demands. Although overall exertion may comprehensively describe the task, local exertion, in conjunction with the knowledge that as load increases more local sites of exertion are reported, may better indicate how increasing muscle strain and increasing straining sites together describe short term, high intensity work.

Tally of Local Exertion Sites Reported

Under all load carriage conditions subjects were asked to report sites where they experienced local exertion. Of the sites reported, 70.9% were upper-limb related, 16.9% back-related and 5.8% lower-limb related. Sites that were reported and comprised less than 1% of the total tally were ignored and this component made up 6.4% of the total number of sites reported (Figure 18).

Chi squared statistical analysis revealed that no significant differences existed in the number of sites reported for the four different load carrying methods. This same analysis showed a significant increase in the number of local exertion sites reported when loads were incremented. The distinct possibility exists, therefore, that the increasing number of sites of local exertion may make a major contribution in influencing ratings of local and overall exertion as loads become heavier.

Static muscle contractions are known to impede blood flow and when high percentages of maximal exertion are demanded the sustained effort is reduced dramatically as a lack of oxygen and the build-up of waste products induce pain which limits the performance (Grandjean, 1973). The present study clearly indicated that the increasing number of sites experiencing local fatigue, as well as the increasing effort demanded by the muscles as load increases are responsible for the increase seen in perceptions of exertion as load increases (see Figure 17).

Table VII: Tally of local exertion sites for incremented loads across methods.

Lateral carrying methods.								
	Unilateral				Bilateral			
Load	P	P25	P50	P75	P	P25	P50	P75
Number of sites	20	34	46	51	15	25	37	47
Frontal carrying methods.								
	Flexed				Extended			
Load	P	P25	P50	P75	P	P25	P50	P75
Number of sites	21	36	48	55	18	36	50	58

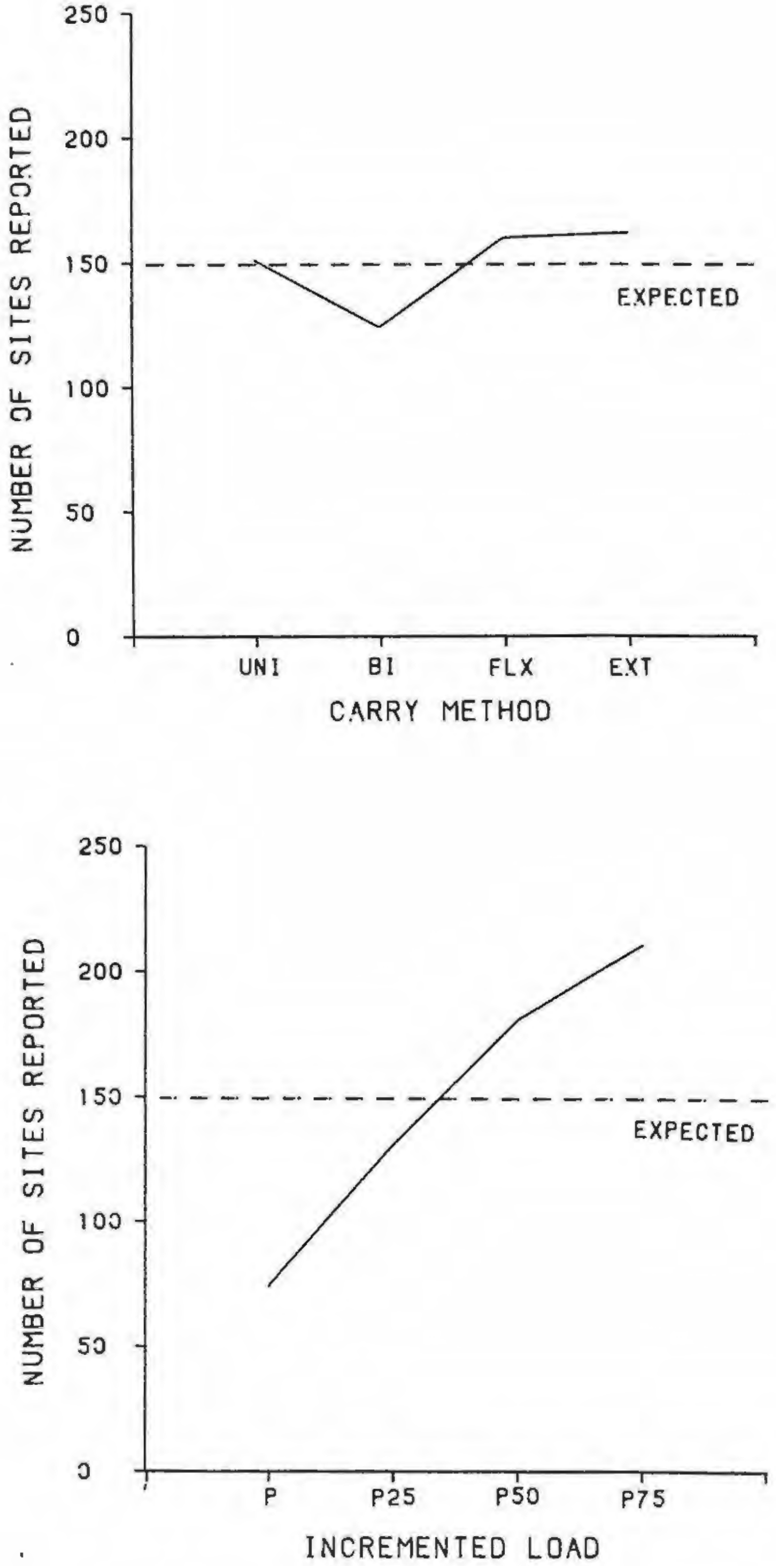


Figure 17: Effects of load and of carrying method on the number of local sites of exertion reported.

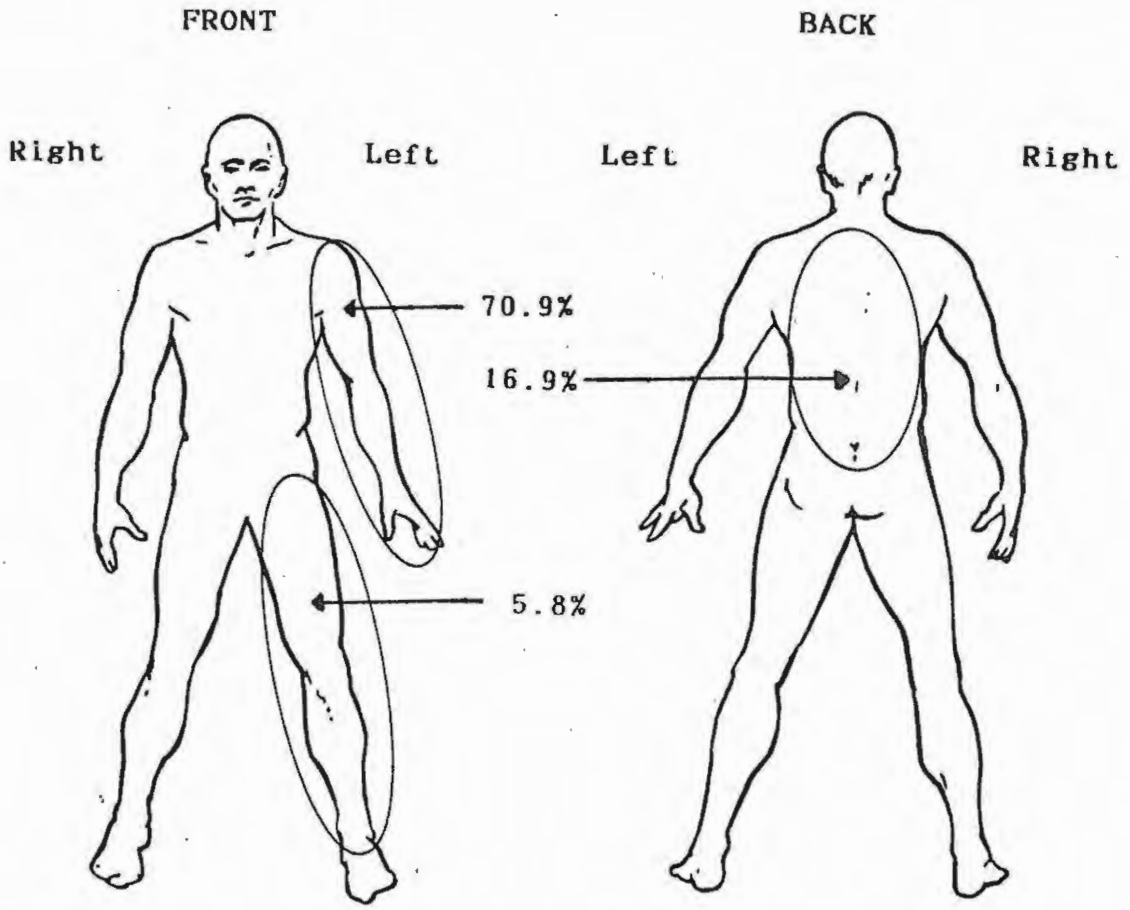


Figure 18: Summary of local exertion sites as a percentage of total sites reported.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The aim of this study was to examine changes in selected gait kinematic and psychophysical parameters of males and females in response to carrying loads that were considered to be above MAL values for a number of load carry methods. Furthermore, this study considered differences in male and female anthropometry and measured strength values (in absolute and relative terms), as well as the magnitude of loads selected by both sexes for the four load-carry methods.

A sample of 10 male and 10 female volunteers between the ages of 18 and 30 was obtained from the student population at Rhodes University. Data were recorded over four sessions. In the first, basic anthropometric and strength data were recorded and subjects were grouped according to sex. In session two subjects were asked to establish maximal acceptable loads (MAL) and absolute maximum loads (AML) for each of the carrying methods. For the lateral carrying methods a standard tool box was used while for the frontal carrying methods a metal basket was carried. For the selection of MAL and AML values subjects were able to add or remove lead shot from the containers until they were content with the load carry mass. Sessions three and four involved the collection of kinematic and psychophysical parameters under unloaded and loaded conditions, over a 10 meter walking distance. The gait kinematics and perceptions of exertion in response to loads based on the range between AML and MAL were measured under each of the carrying method conditions.

Presentation of the load conditions was randomised and the speed at which each condition was executed was recorded. A photocell-triggered timing system was used to determine the walking speed in the target zone on the walkway, while a multichannel biological recorder indicated resistance changes in the system when the conductive tape under the subject's feet made contact with the foil walkway. A sonic digitizer was used to enter the temporal data recorded on the strip-chart into an Apple IIe microprocessor for reduction. Three to five strides were digitized and the data averaged for each condition. Statistical treatment of the gait kinematic, psychophysical and load selection data involved the use of Student's t-tests, and one- and two-way ANOVAs (repeated measures). A chi-squared non-parametric test was used to analyse the tally of local sites of exertion reported, while further t-tests were used to analyse anthropometric and strength data.

Across the various load-carriage methods (at walking speeds based on a "freedom-to-choose" protocol) and incremented load impositions, both sexes chose walking speeds not significantly different from the unloaded walking condition. Carriage methods, however, were seen to be distinctly different from one another by virtue of the fact that significantly different masses were typical of each method. The carrying methods under investigation greatly influenced the gait kinematics of both sexes, whereas mass carried in general did not influence the kinematics of gait to the same extent. However, the males were significantly affected to a greater extent than females, probably owing to their choice of relatively heavier loads. Both heavy loads and awkward carrying methods caused the subjects to take short, fast steps and to assume accomodative postures to shift the centre of mass over the base of support. A number of kinematic parameters demonstrated the inherent stability of the gait pattern. Although initially the carrying of loads disturbs the normal gait kinematic equilibrium, further increases in load under awkward carrying methods resulted in little significant change.

The MAL values chosen by subjects were consistent with the literature (Snook, 1978). However, included in this load choice were ratings of perceived exertion (RPE) describing the stress of the task. This study demonstrated that MAL was rated as "very light" (9), while P75 values were rated as "hard" (15). The distribution of local fatigue was 70% upper limb related; 16% back related; and 5% lower limb related. The AML and MAL values chosen by males were significantly greater than those chosen by females in absolute and also relative terms. This latter difference highlights the fact that males have greater experience in lifting and carrying, probably as a consequence of being more frequently involved in this type of activity.

In absolute terms the males were bigger, stronger and faster. However, when speeds were relativised for stature, and measured strength (hand-grip) for stature, lean body mass and upper body mass distribution (acromial width), the differences in speed and strength became negligible and consequently the sexes could be considered comparable in these parameters. Finally, evidence for maximal effort by the subjects may be infered from the fact that both sexes significantly exceeded, in unimanual load, the hand-grip strength values recorded on the dynamometer.

Hypothesis one proposed that the kinematic and psychophysical dependent variables would not be significantly different across the four carrying methods. This hypothesis was retained in respect of psychophysical parameters measured, but rejected for the locomotor kinematic variables as the majority of the measures taken were significantly different. This conclusion held for both sexes.

Hypothesis two proposed that the kinematic and psychophysical dependent variables would not be significantly different across the four incremented load conditions. For both sexes this hypothesis was rejected in respect of psychophysical parameters measured. However, for the females this hypothesis was retained in regard to the kinematic data, as the magnitude of the loads chosen did not significantly alter the majority of the kinematic measures taken. For the males, however, the null hypothesis was rejected as the relatively heavier loads chosen by this group brought about a significant number of gait kinematic changes.

Hypothesis three proposed that males and females exhibited identical morphology-normalised strength and load preference capacity. This hypothesis was accepted in regard to morphology-normalised strength, but rejected for the preference of load capacity.

This study has shown that different load carrying methods and increasing loads may significantly influence the kinematics of gait. Methods that restrict lower limb excursions (frontal methods) affect gait kinematics more readily than methods that allow free lower limb movements (lateral methods). Heavy loads (P50, P75) bring about a greater number of significant changes to the kinematics of gait than lighter loads (P, P25). As loads increase, so do perceptions of exertion. Also the number of local exertion sites recorded increases significantly. However, different methods of load carriage do not affect ratings of perceived exertion. Males are generally absolutely bigger and stronger than females and consequently are generally more suited to industrial tasks involving manual materials handling (MMH). When compared to females, males chose significantly heavier MALs and AMLs and in so doing demonstrated superiority in load bearing capacity. In relative terms, females were equally strong and many MMH tasks may fall within the acceptable strength envelope of this sex.

RECOMMENDATIONS

The present study clearly indicates the need to develop new measurement techniques that can accommodate the assessment of maximal eccentric strength. Maximum strength values obtained in this manner may better approximate the typical values obtained under maximal load carrying conditions. Although this study investigated the more gross aspects of gait, a more detailed description of gait using more advance technologies may add considerably to the findings described here. Further research in this area could also focus on the tendency for people to retain velocities of load carriage not significantly different from unloaded walking speeds even when awkward, heavy loads are carried. Finally, it would be useful to conduct similar research on larger sample sizes, as well as different population groups (especially those who are employed in occupational MMH), as different populational morphologies and occupational experience may influence the performance of lift-and-carry tasks which form a critical component in many work settings both in the formal and informal sectors.

REFERENCES

Andersson, G.B.J. (1985) Posture and compressive spine loading: intradiscal pressures, trunk myoelectric activities, intra-abdominal pressures and biomechanical analysis. Ergonomics 28: 91-93.

Andersson, G.B.J. (1985) Permissible loads: biomechanical considerations. Ergonomics 28: 323-326.

Åstrand, P.O. and Rodahl, K. (1977) Textbook of Work Physiology, Second Edition. New York: McGraw-Hill Inc.

Biering-Sorensen, F. (1985) Risk of back trouble in individual occupations in Denmark. Ergonomics 28: 51-60.

Borg, G. (1970) Perceived exertion as an indicator of somatic stress. Scandinavian Journal of Rehabilitative Medicine 2-3: 92-98.

Broer, M.R. and Zernicke, R.F. (1979) Efficiency of Human Movement, Fourth Edition. Philadelphia: Saunders College Publishers.

Carter, J.E.L. (1975) The Heath-Carter Somatotype Method. California: San Diego State University.

Carton, R.L. and Rhodes, E.L. (1985) A critical review of the literature on rating scales for perceived exertion. Sports Medicine 2: 198-222.

Celentano, E.J. and Nottrodt, J.W. (1984) OPSS: Description of trade-specific requirements. DCIEM Report, No. 84-12-58.

Chaffin, D.B., Herrin, G.D. and Monroe-Keyserling, W. (1978) Pre-employment strength testing. Journal of Occupational Medicine 20: 403-408.

Charness, N. (1985) Aging and Human Performance. Chichester: John Wiley and Sons Ltd.

Charteris, J., Cooper, L.A. and Bruce, J.R. (1976) Human kinetics: A conceptual model for studying human movement. Journal of Human Movement Studies 2: 233-238.

Charteris, J., Nottrodt, J.W. and Scott, P.A. (under review) The "free-ride" hypothesis: A second look at the efficiency of African women headload carriers. South African Journal of Science.

Charteris, J., Percy-Lancaster, R., Scott, P.A. and Williams, M. (1988) A case study: Asymmetry of foot-floor contacts in a young athlete five years after traumatic lesion to the sciatic nerve. The Journal of Orthopaedic and Sports Physical Therapy 9: 375-380.

Charteris, J., Scott, P.A. and Wall, J.C. (1986) Headloading in Africa: Preliminary findings on the locomotor effects of occupational headload carriage. South African Journal of Physiotherapy 42: 19-24.

Ciriello, V.M. and Snook, S.H. (1983) A study of size, distance, height and frequency effects of manual handling tasks. Human Factors 25: 473-483.

David, G.C. (1985) U.K. National statistics on handling accidents and lumbar back injuries at work. Ergonomics 28:9-16.

Davis, P.R. (1985) The Commission of the European Communities Seminar on the prevention of lumbar disorders at work. Ergonomics 28: 1-2.

Deeb, J.M., Drury, C.G. and Begbie, K.L. (1985) Handle positions in a holding task as a function of task height. Ergonomics 28: 747-763.

Drury, C.G. (1985) The role of the hand in manual materials handling. Ergonomics 28: 1213-1227.

Drury, C.G., Law, C.H. and Pawenski, C.S. (1983) A survey of industrial box handling. Human Factors 25: 553-565.

Drury, C.G. and Pizatella, T. (1983) Hand placement in manual materials handling. Human Factors 25: 557-562.

Evans, W.J., Winsmann, F.R., Pandolf, K.B. and Goldman, R.F. (1980) Self-paced hard work comparing men and women. Ergonomics 23: 613-621.

Ferguson, G.A. (1981) Statistical Analysis in Psychology and Education, Fifth Edition. Singapore: McGraw-Hill Inc.

Frankel, W.H. and Nordin, M. (1980) Basic Biomechanics of the Skeletal System. Philadelphia: Lea and Febiger.

Gamberale, F. (1985) The perception of exertion. Ergonomics 28: 299-308.

Garg, A., Mital, A. and Asfour, S.S. (1980) A comparison of isometric strength and dynamic lifting capability. Ergonomics 23: 13-27.

Garg, A. and Saxena, U. (1980) Container characteristics and maximum acceptable weight of lift. Human Factors 22: 487-495.

Gordon, M.J., Goslin, B.R., Graham, T. and Hoare, J. (1983) Comparison between load carriage and grade walking on a treadmill. Ergonomics 26: 289-298.

Grandjean, E. (1973) Ergonomics of the Home. London: Taylor and Francis Ltd.

Grandjean, E. (1980) Fitting the Task to the Man. An Ergonomic Approach. London: Taylor and Francis Ltd.

Grieve, D.W. and Gear, R.J. (1966) The relationship between length of stride, step frequency, time of swing and speed of walking for children and adults. Ergonomics 5: 379-399.

Griffin, A.B., Troup, J.D.G. and Lloyd, D.C.E.F. (1984) Tests of lifting and handling capacity. Their repeatability and relationship to back symptoms. Ergonomics 27: 305-320.

Jaing, B.J., Smith, J.L. and Ayoub, M.M. (1986) Psychophysical modelling for combined manual materials handling activities. Ergonomics 29: 1173-1190.

Kinoshita, H. (1985) Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. Ergonomics 28: 1347-1362.

Legg, S.J. (1985) Comparison of different methods of load carriage. Ergonomics 28: 1197-1212.

Legg, S.J. and Mahanty, A (1985) Comparison of five modes of carrying a load close to the trunk. Ergonomics 28: 1653-1660.

Legg, S.J. and Pateman, C.M. (1985) Human capabilities in repetitive lifting. Ergonomics 28: 309-321.

Maloiy, G.M.O, Heglund, N.C., Prager, L.M., Cavagna, G.A. and Taylor, C.R. (1986) Energetic cost of carrying loads: have African women discovered an economic way? Nature 319: 668-669.

Martin, P.E. and Nelson, R.L. (1986) The effect of carried loads on the walking patterns of men and women. Ergonomics 29: 1191-1202.

McArdle, W.D., Katch, F.I. and Katch, V.L. (1986) Exercise Physiology, Second Edition. Philadelphia: Lea and Febiger.

Metzler, F. (1985) Epidemiology and statistics in Luxembourg. Ergonomics 28: 21-24.

Military-Standard-1472C (1984) Human engineering design criteria for military systems, equipment and facilities. Washington: Department of Defence.

Mital, A. and Manivasagan, I. (1983) Maximum acceptable weight of lift as a function of material density, centre of gravity location, hand preference and frequency. Human Factors 25: 33-42.

Monod, H. and Zerbib, Y. (1985) Sex-related differences in the manual carriage of loads. Ergonomics 28: 1125-1129.

Murray, M.P. (1966) Gait as a total pattern of movement. American Journal of Physical Medicine 46: 290-333.

Napier, J. (1967) The antiquity of human walking. Scientific American 26: 56-66.

National Institute of Occupational Safety and Health (NIOSH) (1981) Work practice guide for manual lifting. NIOSH Technical Report. Cincinnati, Ohio: Department of Health and Human Services.

Nicholson, A.S. (1985) Accident information from four British industries. Ergonomics 28: 31-34.

Noble, B.J. (1982) Clinical applications of perceived exertion. Medicine and Science in Sport and Exercise 14: 406-411.

Nottrodt, J.W., Charteris, J. and Wall, J.C. (1982) The effects of speed on pelvic oscillations in the horizontal plane during level walking. Journal of Human Movement Studies 8: 27-40.

Nottrodt, J.W. and Manley, P.C. (under review) Reliability of acceptable loads and locomotor patterns in different carriage methods. Ergonomics.

Nottrodt, J.W. and Manley, P.G. (under review) Acceptable loads and locomotor patterns of males and females performing various carriage tasks. Human Factors.

Oguro, Y. (1982) A study of walking width, time and speed in manual load carrying. Proceedings: International Ergonomics Association, Eighth Congress: 266-267.

Pandolf, K.B. (1978) Influence of local and central factors in dominating rated perceived exertion during physical work. Perceptual and Motor Skills 46: 683-698.

Pierrynowski, M.R., Winter, D.A. and Norman, R.W. (1980) Transfers of mechanical energy within the total body and mechanical efficiency during treadmill walking. Ergonomics 23: 147-156.

Pierrynowski, M.R., Norman, R.W. and Winter, D.A. (1981) Mechanical energy analysis of the human during load carriage on a treadmill. Ergonomics 24: 1-14.

Rajeski, W.J. (1981) The perception of exertion: A social-psychophysical integration. Journal of Sport Psychology 4: 305-320.

Rajeski, W.J. (1985) Perceived exertion: An active or passive process? Journal of Sport Psychology 7: 371-378.

Robertson, R.J. (1982) Central signals of perceived exertion during dynamic exercise. Medicine and Science in Sport and Exercise 14: 390-396.

Rosenrot, P. (1980) Asymmetry of Gait and Lower Limb Dominance. Unpublished Master's Thesis, University of Guelph, Canada.

Rosenrot, P., Wall, J.C. and Charteris, J. (1980) The relationship between velocity, stride time, support time and swing time during normal walking. Journal of Human Movement Studies 6: 323-335.

Snook, S.H. (1978) The design of manual handling tasks. Ergonomics 21: 963-985.

Snook, S.H. (1985) Psychophysical considerations in permissable loads. Ergonomics 28: 327-330.

Snook, S.H. and Ciriello, V.M. (1974) Maximal weights and work loads acceptable to female workers. Journal of Occupational Medicine 16: 527-534.

Snook, S.H., Irvine, C.H. and Bass S.F. (1970) Maximum weight and workloads acceptable to male industrial workers. American Industrial Hygiene Association Journal 31: 579-586.

Sperryn, R.N. (1983) Sport and Medicine. London: Butterworths.

Sutherland, D.H., Olshen, R., Cooper, L. and Woo, S.L.Y. (1980) The development of mature gait. The Journal of Bone and Joint Surgery 62: 336-353.

Wall, J.C., Charteris, J. and Hoare, J.W. (1978) An automated on-line system of measuring the temporal patterns of foot/floor contact. Journal of Medical Engineering Technology 2: 187-190.

Wall, J.C., Dhanedran, M. and Klenerman, L. (1976) A method of measuring the temporal/distance factors of gait. Biomedical Engineering 11: 409-412.

Wall, J.C., Nottrodt, J.W. and Charteris, J. (1981) The effects of uphill and downhill walking on pelvic oscillations in the transverse plane. Ergonomics 24: 807-816.

Wells, L.L. and Plowman, S.A (1983) Sexual differences in athletic performance: Biological or behavioural? The Physician and Sports Medicine 11: 52-63.

Zerbib, Y., Evans, O.M. and Monod, H. (1983) Heart rate responses to a repetitive load carrying task. Journal of Human Ergology 12: 131-141.

APPENDIX A

Borg's Rating of Perceived Exertion Scale

RPE SCALE

6	
7	VERY, VERY LIGHT
8	
9	VERY LIGHT
10	
11	FAIRLY LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD
16	
17	VERY HARD
18	
19	VERY, VERY HARD
20	

APPENDIX B

Informed consent and subject consent sheet

RHODES UNIVERSITY

DEPARTMENT OF HUMAN MOVEMENT STUDIES

INFORMED CONSENT INFORMATION SHEET

TITLE: Effects of increases in load over prefered values on selected psychophysical and biomechanical parameters.

GENERAL: This study will examine whether incremental loads greater than prefered values will significantly alter selected gait kinematic patterns as well as psychophysical perceptions of local and overall exertion. A prefered load as defined for this study will be the maximal freely accepted load (MAL) that the subject elects to carry and to do so comfortably. Participation as a subject is entirely voluntary and subjects are free to withdraw at any time during the study.

PROCEEDURE: Subjects will be asked to participate in four data collection sessions of approximately forty minutes in duration.

1. During the first data collection session the following parameters will be collected: age, gender, body mass, stature, arm length, biacromial width, bi-iliac width, chest and abdominal girths, hand dominance and left and right hand grip strengths.

2. During the second data collection session the MAL for each load carry method will be established as well as maximal voluntary carry limit values.

3. Data collection sessions three and four will be used to collect the gait kinematics for normal unloaded walking, MAL carriage and incremental loads for the four load carriage

tasks. Also in these sessions psychophysical perceptions of local and overall exertion will be obtained.

4. To establish the MAL for each carry method subjects will be made familiar with the carriage method requirements and the proceedure of adding or subtracting lead shot from the containers.

5. Selection of the prefered load weight will be determined by walking with the load over a 10m walkway where at either end the weight can be adjusted to acceptable comfort.

6. The speed at which subjects will carry the loads will be of free choice, however the same speed will be used during the data collection trial. Three preparatory trials will be conducted to establish prefered speeds. During a fourth trial kinematic and psychophysical parameters will be collected.

7. The following load carry methods will be studied:
   a) Carriage of a load in the prefered hand by the subject's side (UNI)
   b) Carriage of separate loads in both hands at the subject's sides (BI)
   c) Carriage of a load in front of the subject with both hands and arms bent at 90° (FLX)
   d) Carriage of a load in front of the subject with both hands and arms extended (EXT)

8. You are required to inform the experimenter of any injury or illness occuring prior to or during a testing session.

9. For your protection you will be required to wear protective footwear when establishing maximal carry limits.

RISKS: When carrying loads slipping of the feet or the load from the hands is possible. However regular cleaning of the walkway of dust, as well as subjects wearing special non-slip rubberised socks will reduce the possibility of the feet slipping. As stated earlier, subjects are required to wear protective footwear when establishing voluntary carry limit values. However, when loads are carried without protective footwear load masses will be below carry limit values. The handles chosen for this study are comfortable and meet regulation standards. Furthermore, a spotter will walk beside the subjects to assist them if necessary.

BENEFITS: On completion of the study subjects are at liberty to request information relating to their load carriage capabilities, as well as their responses to excessive loading under various conditions. This knowledge may help in recognising potentially hazardous manual materials handling situations.

RHODES UNIVERSITY

DEPARTMENT OF HUMAN MOVEMENT STUDIES

SUBJECT CONSENT FORM

I,

having been fully informed of the nature of the research entitled:

EFFECTS OF INCREASES IN LOAD OVER PREFERRED VALUES ON SELECTED PSYCHOPHYSICAL AND BIOMECHANICAL PARAMETERS.

do hereby give my consent to act as a subject in the abovenamed research.

I am fully aware of the procedures involved as well as the potential risks and benefits attendant to my participation as explained to me verbally and in writing. In agreeing to participate in this research, I waive any legal recourse against the researchers or Rhodes University, from any and all claims resulting from personal injuries sustained. This waiver shall be binding upon my heirs and personal representatives. I realize that it is necessary for me to promptly report to the researcher any signs or symptoms indicating any abnormality or distress.

I am aware that I may withdraw my consent and may withdraw from participation in the research at any time. I am aware that my anonymity will be protected at all times, and agree that the information collected may be used and published for statistical or scientific purposes.

I have read the information sheet accompanying this form and understand it. Any questions which may have occurred to me have been answered to my satisfaction.

Subject (or legal representative):

______________	______________	
(PRINT NAME)	(SIGNED)	(DATE)

Person administering informed consent:

______________	______________	
(PRINT NAME)	(SIGNED)	(DATE)

Witness:

______________	______________	
(PRINT NAME)	(SIGNED)	(DATE)

Project Supervisor:

______________	______________	
(PRINT NAME)	(SIGNED)	(DATE)

APPENDIX C

Table of means for all parameters measured

Table VIII: Table of means for all parameters measured
(mean and standard deviation).

			UNI					BI					FLX					EXT				
		Normal	MAL	P25	P50	P75	MAX	MAL	P25	P50	P75	MAX	MAL	P25	P50	P75	MAX	MAL	P25	P50	P75	MAX
Cadence	M	110.6/10.0	117.3/12.7	119.2/14.3	124.7/19.6	136.3/21.6		114.1/15.0	119.8/16.5	125.2/22.0	131.9/19.7		122.4/19.2	128.3/18.8	131.8/22.4	136.8/23.9		130.9/18.8	133.2/17.8	137.2/18.4	142.3/19.1	
(statures.min^{-1})	F	109 /5.7	114.1/9.9	113.0/9.0	117.2/11.6	125.5/16.2		117.3/7.9	117.7/9.4	120.4/8.9	124.5/12.3		124.6/10.9	124.2/6.0	129.2/9.2	128.8/9.8		122.5/7.2	124.5/7.9	133.6/10	126.9/9.5	
Stride length	M	127.4/15.6	126.4/12.5	122.3/11.9	121.5/10.2	114.1/15.4		124.7/15.1	125.5/13.6	124.2/14.2	121.2/13.7		117.4/11.6	113.6/10.2	112.9/12.8	108.5/13.5		105.8/13.7	103.2/12.2	100.1/13.1	92.3 /10.6	
(cm)	F	128 /14.4	118.8/7.5	118.9/7.3	116.4/5.3	114.7/8.5		123.2/8.3	120.8/6.8	120.9/6.0	117.4/6.5		111.1/10.9	113.5/8.6	109.9/5.9	111.9/7.5		104.3/4.8	103.3/4.6	101 /4.8	99.1 /5.7	
Velocity	M	1.20 /0.22	1.25 /0.23	1.24 /0.25	1.28 /0.27	1.31 /0.3		1.20 /0.28	1.27 /0.28	1.30 /0.29	1.35 /0.29		1.22 /0.26	1.23 /0.25	1.25 /0.25	1.24 /0.23		1.17 /0.27	1.15 /0.22	1.15 /0.22	1.1 /0.16	
(m.s^{-1})	F	1.17 /0.11	1.13 /0.1	1.13 /0.08	1.14 /0.12	1.20 /0.14		1.21 /0.11	1.19 /0.1	1.22 /0.07	1.22 /0.1		1.15 /0.09	1.18 /0.1	1.19 /0.8	1.20 /0.08		1.07 /0.06	1.08 /0.06	1.04 /0.08	1.05 /0.07	
Double support	M	26 /3.4	25.9 /2.5	28.5 /2.1	27.7 /2.7	31.5 /5.5		30.2 /3.7	29.9 /4.2	29.5 /3.6	29.7 /4.4		26.8 /2.7	28 /3.6	30.5 /9.6	30.5 /5.7		25.9 /3.7	27.1 /5.1	27 /5.6	31.4 /5.8	
(% stride time)	F	27 /4.0	28.45/5.8	28.83/5.9	28.48/3.2	31.8 /9.0		28.35/4.7	30.15/5.3	29.76/5.2	29.4 /3.2		28.2 /3.3	27.2 /2.4	28.4 /3.6	27.1 /4.4		24.9 /2.2	26.3 /3	27.3 /2.3	31 /9.6	
Stride time	M	1.08 /0.09	1.03 /0.11	1.02 /0.12	0.98 /0.15	0.897/0.14		1.06 /0.13	1.01 /0.12	0.97 /0.14	0.923/0.12		0.95 /0.15	0.94 /0.13	0.92 /0.15	0.896/0.14		0.93 /0.13	0.91 /0.12	0.89 /0.12	0.853/0.1	
(s)	F	1.09 /0.05	1.05 /0.1	1.05 /0.09	1.02 /0.11	0.965/0.11		1.02 /0.07	1.02 /0.08	0.99 /0.07	0.968/0.09		0.98 /0.11	0.963/0.04	0.93 /0.06	0.932/0.06		0.98 /0.06	0.934/0.05	0.946/0.06	0.946/0.06	
Relative speed	M	0.678/0.12	0.707/0.12	0.702/0.13	0.72 /0.14	0.741/0.15		0.681/0.15	0.719/0.15	0.74 /0.18	0.764/0.15		0.69 /0.14	0.69 /0.14	0.71 /0.14	0.701/0.12		0.66 /0.14	0.65 /0.11	0.65 /0.12	0.622/0.08	
(statures.s^{-1})	F	0.705/0.06	0.68 /0.06	0.68 /0.05	0.69 /0.07	0.727/0.08		0.73 /0.07	0.717/0.06	0.73 /0.04	0.738/0.07		0.69 /0.05	0.74 /0.06	0.716/0.05	0.728/0.04		0.64 /0.04	0.65 /0.04	0.628/0.05	0.635/0.04	
Support-swing	M	1.74 /0.13	1.78 /0.13	1.8 /0.117	1.9 /0.17	2.06 /0.41		1.92 /0.17	1.9 /0.18	1.96 /0.2	1.94 /0.18		1.77 /0.11	1.8 /0.14	1.82 /0.2	1.91 /0.18		1.84 /0.27	1.79 /0.25	1.81 /0.22	2.04 /0.34	
ratio	F	1.67 /0.12	1.83 /0.22	2.05 /0.78	1.86 /0.22	2.14 /0.78		1.91 /0.44	1.88 /0.27	1.95 /0.35	1.90 /0.25		1.88 /0.3	1.74 /0.18	1.8 /0.18	1.78 /0.24		1.73 /0.09	1.75 /0.12	1.85 /0.28	1.90 /0.21	
Total support	M	63.6 /1.6	64 /1.76	64.3 /1.5	65.5 /2.06	67 /3.6		65.7 /2.05	65.4 /2.2	66.2 /2.2	66.0 /2.2		64 /1.4	64.3 /1.8	64.5 /2.6	65.6 /1.9		64.6 /3.2	64.0 /3.2	64.3 /2.7	66.8 /3.4	
(% cycle time)	F	62.5 /1.7	64.6 /2.4	66.1 /5.4	64.9 /2.4	67.1 /5.2		65.2 /3.9	65.1 /2.9	65.8 /3.4	65.5 /2.5		65.1 /3.2	63.5 /2.3	64.3 /2.3	63.9 /2.7		63.5 /1.2	63.6 /1.5	64.7 /3.5	65.5 /2.3	
verall RPE	M		9.7 /1.0	12 /2.3	13.7 /2.8	15.1 /2.3		9.1 /1.6	11.1 /1.3	13.5 /1.5	15.4 /2.1		9.6 /1.4	12.2 /1.8	14 /1.8	15.2 /2.0		9.9 /1.8	12.4 /1.7	14.4 /1.6	16.4 /2.1	
	F		10 /1.5	11.3 /1.8	12.8 /1.9	14.4 /2.5		9.9 /1.5	12 /1.69	13.7 /1.8	15.4 /1.4		9.8 /1.8	11.2 /1.4	12.5 /1.8	14.1 /1.4		10.5 /2.5	12.2 /2.2	14.1 /1.9	15.6 /1.5	
ocal RPE	M		8.9 /2.9	11.5 /3.4	13.4 /3.3	16 /1.9		7 /1.8	10 /2.9	13.5 /1.9	15.7 /1.9		9.8 /3.0	12.2 /2.8	14.5 /1.5	15.7 /2.1		9.5 /2.6	12.4 /2.0	14.3 /1.7	16 /2.1	
	F		9.8 /2.4	12.6 /1.5	13.7 /1.4	15.7 /1.7		7.5 /2.3	10.8 /3.1	13.7 /2.1	15 /1.8		9 /2.7	11.4 /1.4	12.9 /1.8	14.2 /2.0		9 /2.8	11.9 /2.7	14 /1.8	14.8 /1.8	
bsolute mass	M		26.1 /8.7	34.6 /7.9	43.1 /7.5	51.6 /7.6	60 /8.1	49.4 /10.4	63.3 /10.2	77.2 /10.5	91.4 /10.8	105.4/11.7	36.1 /5.9	45 /6.6	53.8 /8.8	62.7 /11.6	71.8 /15.2	43.5 /9.3	55.6 /8.4	67.9 /9.1	80.1 /11.1	92.4 /14.0
kg)	F		18 /4.8	21.9 /4.5	25.9 /4.8	29.9 /5.3	33.9 /6.0	34.9 /6.9	41.7 /8.3	49.5 /9.9	57.2 /11.8	65.5 /13.8	22.7 /4.9	26.7 /5.3	30.8 /5.6	34.8 / 6.4	38.8 /7.2	26.3 /5.4	31.7 /6.1	37.1 /7.0	42.5 /8.2	47.7 /9.2
elative mass	M		35.2 /8.4	47.2 /7.2	59 /7.4	71 /8.8	82.9 /11.3	67.6 /9.7	86.9 /9.4	106 /10.6	126 /12.5	145.2/15.2	49.6 /5.2	62 /7.6	74.3 /11.6	86.8 /16.3	95.5 /22.0	59.2 /7.4	76.5 /5.0	93.1 /7.7	110.3/12.6	127.4/17.9
% body mass)	F		30.8 /8.1	37.8 /8.4	44.3 /8.7	51.3 /9.8	58.3 /11.0	58.1 /12.5	71.2 /14.3	84.5 /17.8	97.9 /22	111.3/25.6	38.9 /8.1	45.7 /8.4	52.5 /9.4	59.4 /11.0	66.3 /12.3	45.1 /8.0	54.1 /9.5	63.1 /11.3	72.6 /13.6	81.4 /16
elative mass	M		100 /0.0	135.9/14.7	171.9/29.2	208.2/46.2	244.5/59/0	100 /0.0	128.7/8.1	158 /16.2	188.1/25	218.3/33.2	100 /0.0	124.9/10.8	149.9/21	175.2/31.4	201.7/43.0	100 /0.0	129.5/14.4	159.9/29.1	189.9/43.5	220.6/58.6
% MAL)	F		100 /0.0	122.8/9.8	146.6/19.3	170 /29	194.8/38.0	100 /0.0	122.6/8.2	146.3/16.6	169.8/24.7	193.5/33.1	100 /0.0	117.3/6.4	136.3/13.7	154.7/20.6	163.2/24.1	100 /0.0	120.5/5.4	141 /10.6	161.9/16.0	182.1/20.5

APPENDIX D

Computer listings:

1. Timing between LEDs
2. Menu alignment
3. Analyse heel-ball-toe

```
10  REM  *****************
20  REM  *** TIMER.BAS ***
30  REM  *****************
40  POKE 33,40: POKE 34,0:      HOME
     :D$ =  CHR$ (4)
50  PRINT D$;"BLOAD TIMA.B      I
     N"
60  HTAB 5: INVERSE : PRIN      T
     "TIMING WITH THE APPL      E
     ": NORMAL
70  PRINT : PRINT "THIS PR      O
     GRAM MAY BE USED TO O      B
     TAIN THE  TIME (IN SE      C
     S) THAT IT TAKES FOR       A
           SUBJECT TO PASS
     BETWEEN THE TWO L..E.D     .
     'S"
79  PRINT
80  PRINT "ONCE THE SUBJEC      T
      HAS PASSED THE SECON      D
       L.E.D., THE TIME WI      L
     L BE DISPLAYED ON   T      H
     E SCREEN."
90  PRINT : INVERSE : PRIN      T
     "YOU MAY BEGIN WHENEV      E
     R YOU ARE READY": NOR      MAL

100  CALL 24320
110 TIME = (( PEEK (24075)       *
     256) +  PEEK (24074))       /
     1000
120  PRINT : PRINT "TIME (      S
     ) = ";TIME
130  PRINT : INPUT "DO YOU
     WISH TO RE-RUN THE PR      O
     GRAM(Y/N)?":AN$
140  IF AN$ <  > "Y" AND A      N
     $ <  > "N" GOTO 130
150  IF AN$ = "Y" THEN  HO      ME
     : GOTO 70
160  HOME : PRINT "THE END      "
     : END
```

```
10  REM  *****************      *
     ******
20  REM  *  MENU ALIGNMENT

30  REM  *****************      *
     ******
32  DATA  160,3,162,186,17      3
     ,0,193,189,0,200,202,      1
     36,48,13
34  DATA    217,41,96,240,      2
     44,238,06,96,173,06,9      6
     ,201,200,173,06,96
36  DATA   41,07,141,44,96      ,
     173,255,207,144,216,9      6
     ,32,106,202,0
40 D$ =  CHR$ (4)
60  FOR I = 1 TO 45: READ       X
     : POKE (24575 + I),X:       NEXT
     I
70  HOME : TEXT : CALL 245      7
     6:T =  PEEK (24620):       IF
     T < 1 OR T > 8 THEN        HOME
     : VTAB 12: HTAB 5: PR      INT
     "NOT DETECTING INTERF      A
     CE CARD!!!": PRINT :       END

75  HOME : VTAB 10: HTAB 9      :
      FLASH : PRINT " INTE      R
     FACE IN SLOT # ";T;:       PRINT
     " ": NORMAL : FOR I =
     1 TO 2000: NEXT :SL =
     T
80 XOFF = 0:YOFF = 0:SCAL      -=
     20: TEXT : HOME : VTA      B
     2: HTAB 14: PRINT "OV      E
     RLAY ALIGNMENT": HTAB
     14: PRINT "-----------     -
     -------": PRINT : PRIN     T
     : POKE 34,5
90  PRINT D$;"PR#0": HOME       :
     A$ = "PLACE OVERLAY I      N
      CENTER": GOSUB 670:A      $
      = "OF GRAPHICS TABLE      T
      RECESSED AREA": GOSU      B
     670: PRINT
100 A$ = "THEN TAPE UPPER-      L
     EFT CORNER": GOSUB 67      O
     :A$ = "OF OVERLAY TO       T
     ABLET": GOSUB 670: PR      INT
     : PRINT : PRINT ------
```

```
      SPACE BAR TO ACKNOWL        E
      DGE": GOSUB 670:A$ =        "
      THAT YOU HAVE PERFORM       E
      D THIS": GOSUB 670: P       RINT
      : PRINT
120   HTAB 10: INVERSE : PR       INT
      "       SPACE BAR
      ": NORMAL : PRINT : P       RINT

130   HTAB 20: GET A$: IF A       $
       <  > " " THEN 130
135   HOME :A$ = "OK": GOSU       B
      670: FOR I = 1 TO 100       O
      : NEXT
140   HOME : VTAB 8:A$ = "T       A
      KE THE TABLET PEN AND
      PRESS IT": GOSUB 670:       A
      $ = "DOWN AT THE UPPE       R
      -LEFT CORNER": GOSUB        6
      70:A$ = "OF THE RESET
      COMMAND BOX": GOSUB 6       7
      0: GOSUB 540: VTAB 20       :
       PRINT
150   PRINT D$;"PR#";SL: PR       INT
      "T1,X";XOFF;",Y";YOFF       ;
      ",S";SCAL;",R,C,N"
160   PRINT D$;"IN#";SL
170   GOSUB 610:HX = X: REM
       SAVE X-COORD
180   IF Z < 0 THEN  GET A$       :
       IF A$ =  CHR$ (27) T       HEN
       PRINT : GOTO 90
190   IF Z <  > 2 THEN 140
200   PRINT : PRINT D$;"PR#       0
      ": HOME : IF X > 60 O       R
      Y > 60 THEN  HTAB 13:        PRINT
      "NO!  TRY AGAIN!": FO       R
      XX = 1 TO 1000: NEXT        X
      X: GOTO 140
210   PRINT D$;"IN#0":A$ =        "
      GOOD.   NOW...": GOSU       B
      670: FOR XX = 1 TO 10       0
      0: NEXT XX: HOME
220   PRINT : PRINT :A$ = "       P
      RESS THE PEN DOWN AT        T
      HE LOWER-LEFT": GOSUB
      670:A$ = "CORNER OF T       H
      E WORK AREA.": GOSUB        6
      70: GOSUB 570: VTAB 1       3
      : PRINT
230   GOSUB 610: IF Z < 0 T       HEN
       GET A$: IF A$ =  CHR       $
      (27) THEN  PRINT : GO       TO
      90
235   IF Z < 0 THEN  VTAB 2       0
      : PRINT : GOTO 230
240   IF X = HX THEN 300
250   VTAB 12:A$ = "SWING T       H
      E BOTTOM OF THE OVERL       A
      Y AS": GOSUB 670:A$ =
      "INDICATED UNTIL PRES       S
      ING THE PEN DOWN": GO       SUB
      670:A$ = "AT THIS POI       N
      T SHOWS ALIGNED": GOS       UB
      670
```

```
260  VTAB 18: CALL  - 958:      GOSUB
     340: VTAB 18: PRINT       CHR$
     (7): IF X < HX THEN A     $
      = "SWING THE OVERLAY
     RIGHT": GOTO 280
270 A$ = "SWING THE OVERLA     Y
      LEFT"
280  VTAB 18: GOSUB 670: G     OSUB
     610: IF Z < 0 THEN  G     ET
     A$: IF A$ =  CHR$ (27     )
      THEN  PRINT : GOTO 9     0

290  IF HX <  > X THEN 260
300  HOME : VTAB 12:A$ = "     A
     LIGNED": GOSUB 670: G     OSUB
     570: VTAB 15:A$ = "TA     P
     E OVERLAY IN PLACE":      GOSUB
     670:A$ = "AND": GOSUB
     670:A$ = "PRESS THE S     P
     ACE BAR TO ACKNOWLEDG     E
     ": GOSUB 670: VTAB 19     :
      HTAB 10: INVERSE : P     RINT
     "      SPACE BAR
     "
301  NORMAL
310  GOSUB 610: IF Z =  >      0
      THEN  HOME :A$ = "ON     C
     E ALIGNED, DON'T CONF     U
     SE ME!": GOSUB 670: F     OR
     XX = 1 TO 1000: NEXT      X
     X: HOME : GOTO 220
320  GET A$: IF A$ =  CHR$
     (27) THEN 90
330  IF A$ <  > " " THEN       VTAB
     20: PRINT : GOTO 310
340  HGR : PRINT : PRINT D     $
     ;"PR#";SL: PRINT "M1,     X
     0,Y0,S2,R,C"
350  VTAB 21: CALL  - 958:     A
     $ = "PRESS DOWN WITH      T
     HE PEN AT THE FOUR":      GOSUB
     670:A$ = "CORNERS OF      T
     HE OVERLAY AS INDICAT     E
     D.": GOSUB 670
360  VTAB 24: HTAB 10: PRI     NT
     "PRESS ESC TO RE-STAR     T
     .";: VTAB 1: POKE  -      1
     6297,0: POKE  - 16301     ,
     0: POKE  - 16300,0: P     OKE
      - 16304,0
362  HCOLOR= 3: HPLOT 63,1     2
      TO 215,12 TO 215,148      TO
     63,148 TO 63,12
363 XX = (215 - 63) / 22:      FOR
     I = 1 TO 21:YY = 63 +
     XX * I: HPLOT YY,12 T     O
     YY,24: NEXT
365  HPLOT 63,24 TO 215,24     :
      HPLOT 63,18 TO 215,1     8
```

```
 370  HCOLOR= 3:P = 12: GOS          UB
      720: GOSUB 610: HCOLO          R=
      0: GOSUB 720: IF Z <           0
       THEN 680
 380 X1 = X:Y1 = Y: GOSUB 7          1
      0: HCOLOR= 3: GOSUB 7          4

     0: GOSUB 610: HCOLOR=
     0: GOSUB 740: IF Z <            0
      THEN 680
 390 X2 = X:Y2 = Y: GOSUB 7          1
     0: HCOLOR= 3:P = 148:            GOSUB
     740: GOSUB 610: HCOLO           R=
     0: GOSUB 740: IF Z <            0
      THEN 680
 400 X3 = X:Y3 = Y: GOSUB 7          1
     0: HCOLOR= 3: GOSUB 7           2
     0: GOSUB 610: HCOLOR=
     0: GOSUB 720: IF Z <            0
      THEN 680
 410 X4 = X:Y4 = Y: GOSUB 7          1
     0
 420  IF  ABS (X1 - X4) > 3          0
       OR  ABS (X2 - X3) >           3
     0 OR  ABS (Y1 - Y2) >
     30 OR  ABS (Y3 - Y4)            >
     30 THEN 690
 425  IF  ABS (X1 - X2) < 5          0
       OR  ABS (Y2 - Y3) <           5
     0 THEN 690
 430 X1 =  INT ((X1 + X4) /
     2):Y1 =  INT ((Y1 + Y           2
     ) / 2):X2 =  INT ((X2            +
     X3) / 2):Y2 =  INT ((            Y
     3 + Y4) / 2)
 440  HOME : PRINT D$;"PR#0          "
     : TEXT : HOME : VTAB            1
     2:A$ = "CREATING TABL           E
     T INFORMATION FILE.":            GOSUB
     670
 450  ONERR  GOTO 480
 460  PRINT D$;"VERIFY TAB.          I
     NFORMATION,D1"
 470  PRINT D$;"UNLOCK TAB.          I
     NFORMATION"
 480  ONERR  GOTO 800
 490  PRINT D$;"OPEN TAB.IN          F
     ORMATION"
 500  PRINT D$;"WRITE TAB.I          N
     FORMATION"
 510  PRINT SL: PRINT X1: P          RINT
     Y1: PRINT X2: PRINT Y           2

 520  PRINT D$;"CLOSE TAB.I          N
     FORMATION"
 525  PRINT D$;"LOCK TAB.IN          F
     ORMATION"
 530  PRINT : PRINT D$;"RUN
     DIGITIZE"
 540  REM  ****************          *
     ******
 550  REM  * ALIGNMENT REST          A
     RT COMMAND
```

```
 560  REM  ****************       *
      ******
 570  VTAB 22: HTAB 5: PRIN       T
      "IF OVERLAY COMES LOO       S
      E FROM TABLET,": PRIN       T
      : HTAB 9: PRINT "PRES       S
       ";: INVERSE : PRINT        "
      ESC";: NORMAL : PRINT
      " KEY TO RE-TAPE";: R      ETURN
580  REM  ****************       *
     *****
590  REM  *  SINGLE PEN-IN       P
     UT ROUTINE
600  REM  ****************       *
     *****
610  PRINT D$;"PR#";SL: PR       INT
     "N": PRINT D$;"IN#";S       L
     : INPUT X,Y,Z: IF Z =
      > 0 THEN  IF Z <  >        2
      THEN 610
620  PRINT D$;"PR#0": PRIN       T
     D$;"IN#0": RETURN
630  REM  ****************       *
     *********
640  REM  * STRING CENTER        A
     ND PRINT
650  REM  *  WITH CR
660  REM  ****************       *
     *********
670  HTAB 21 - ( LEN (A$)        /
     2): PRINT A$:Z1 =  FR       E
     (0): RETURN
680  GET A$: IF A$ =  CHR$
     (27) THEN  PRINT : GO       TO
     80
690  PRINT : PRINT D$;"PR#       0
     ": TEXT : HOME : VTAB
     2:A$ = "EITHER YOU WE       R
     E NOT VERY CAREFUL, O       R
     ": GOSUB 670: PRINT :       A
     $ = "DID NOT FOLLOW I       N
     STRUCTIONS, OR": GOSU       B
     670: PRINT :A$ = "THE
     OVERLAY IS NOT ALIGNE       D
     .": GOSUB 670: PRINT        :
      PRINT
700 A$ = "TRY IT AGAIN": G       OSUB
     670: FOR XX = 1 TO 25       0
     0: NEXT XX: GOTO 340
710  VTAB 17: PRINT D$;"PR       #
     0": PRINT  CHR$ (7):        PRINT
     D$;"PR#";SL: PRINT "N       "
     : RETURN
720  REM  * RIGHT ARROW *
730  HPLOT 50,P TO 61,P: H       PLOT
     56,P - 5 TO 60,P TO 5       6
     ,P + 5: RETURN
740  REM  * LEFT ARROW *
750  HPLOT 217,P TO 228,P:        HPLOT
     222,P - 5 TO 218,P TO
     222,P + 5: RETURN
```

```
800' TEXT : HOME : VTAB 10        :
      PRINT " UNABLE TO WR        I
     TE DISK INFORMATION F        I
     LE.": PRINT : PRINT
810  HTAB 8: PRINT "CORREC        T
      PROBLEM WITH MEDIA":         PRINT
     : HTAB 11: PRINT "AND
     THEN TYPE 'RUN'.
```

```
10   DIM D(20,12),L(20,16),       R
       (20,16),LM(2,16),RM(2      ,
       16),CK(20,4)
20   ONERR  GOTO 2010
30   POKE 33,40: POKE 34,0:        HOME
       :D$ =  CHR$ (4)
40   HOME : HTAB 6: PRINT "       H
      EEL-BALL-TOE CONTACT        P
      ROGRAM": VTAB 4: FOR        I
       = 1 TO 40: PRINT "-"       ;
      : NEXT : PRINT
50   VTAB 8: PRINT "OPTIONS       :
      ": VTAB 10: PRINT "<1       >
       ANALYSE MOST RECENTL       Y
       DIGITIZED DATA"
60   PRINT "<2> ANALYSE PRE       V
      IOUSLY DIGITIZED DATA       "
      : PRINT
70   PRINT "<3> PRINT RESUL       T
      S OF PREVIOUS ANALYSI       S
      ": PRINT
80   PRINT "<4> DIGITIZE MO       R
      E DATA": PRINT
90   PRINT "<5> QUIT"
100   VTAB 23: INPUT "ENTER
      SELECTION (1-5): ";I:        IF
      I < 1 OR I > 5 GOTO 1       0
      0
110   ON I GOTO 150,230,182       0
      ,120,140
120   HOME : VTAB 12: INVER       SE
      : PRINT "LOADING PROG       R
      AM - PLEASE WAIT": NO       RMAL

130   PRINT D$;"RUN DIGITIZ       E
      ,D1"
140   HOME : PRINT "THE END       "
      : END
150   PRINT D$;"OPEN TEMP.I       N
      FO,D1"
160   PRINT D$;"READ TEMP.I       N
      FO"
170   INPUT F$
180   PRINT D$;"CLOSE TEMP.       I
      NFO"
190   HOME : PRINT "THE FIL       E
       CONTAINING THE MOST        R
      ECENTLY   DIGITIZED D       A
      TA IS": HTAB 10: PRIN       T
      : INVERSE : PRINT F$:        NORMAL
200   PRINT : INPUT "PROCEE       D
```

```
      WITH ANALYSIS (Y/N)?
     ";AN$: IF AN$ <   > "Y     "
      AND AN$ <   > "N" GOT     O
     200
210  IF AN$ = "N" THEN  HO      ME
     : GOTO 50
220  GOTO 260
230  HOME : PRINT "ENTER T      H
     E NAME OF THE FILE CO      N
     TAINING   THE DATA YO      U
      WISH TO ANALYSE"
240  PRINT : INPUT "FILENA      M
     E: ";F$: IF  LEN (F$)       >
     29 THEN  PRINT : INVE      RSE
     : PRINT "ERROR IN FIL      E
     NAME - PLEASE RE-ENTE      R
     ": NORMAL : PRINT : G      OTO
     240
250 OP = 2
260  PRINT : INVERSE : PRI      NT
     "RETRIEVING DATA FROM
     DISC-PLEASE WAIT": NO      RMAL

270  PRINT D$;"OPEN ";F$;"      ,
     D2"
280  PRINT D$;"READ ";F$
290  INPUT N$: INPUT S$: I      NPUT
     AGE: INPUT WT: INPUT       H
     T: INPUT LL: INPUT RL      :
      INPUT LF: INPUT RF
300  INPUT P$: INPUT Y$: I      NPUT
     VEL: INPUT X$: INPUT       D
     IST: INPUT TIME: INPU      T
     PS: INPUT NS
310  FOR I = 1 TO NS: FOR       J
      = 1 TO 12: INPUT D(I      ,
     J): NEXT : NEXT
320  PRINT D$;"CLOSE ";F$
330  HOME : VTAB 10: PRINT
     "DATA ENTRY COMPLETED      "
     : VTAB 12: FLASH : PR      INT
     "CALCULATION BEGINS -
     PLEASE WAIT!": NORMAL

340  IF Y$ = "T" GOTO 360
350 VEL = DIST / TIME
360 REL = (VEL / HT) * 100
370  FOR I = 1 TO NS: FOR       J
      = 1 TO 2:CK(I,2 * J       -
     1) = 9999:CK(I,2 * J)       =
      - 9999: NEXT : NEXT
380  FOR I = 1 TO NS
390  FOR J = 1 TO 6
400  IF D(I,J) > CK(I,2) T      HEN
     CK(I,2) = D(I,J)
410  IF D(I,J) < CK(I,1) T      HEN
     CK(I,1) = D(I,J)
420  IF D(I,J + 6) > CK(I,      4
     ) THEN CK(I,4) = D(I,      J
      + 6)
```

```
430  IF D(I,J + 6) < CK(I,        3
     ) THEN CK(I,3) = D(I,        J
      + 6)
440  NEXT
450  NEXT
460  FOR I = 1 TO NS - 1

470  IF I = 1 GOTO 490
480 L(I,1) = (CK(I - 1,4)         -
     CK(I,1)) / PS
490 L(I,2) = (CK(I,2) - CK        (
     I,1)) / PS
500 L(I,3) = (CK(I + 1,1)         -
     CK(I,2)) / PS:L(I,4)         =
     L(I,2) + L(I,3):L(I,5        )
      = (CK(I + 1,1) - CK(        I
     ,3)) * VEL * 100 / PS        :
     L(I,6) = L(I,4) * VEL         *
     100:L(I,7) = 60 * PS         /
     (CK(I + 1,1) - CK(I,3        )
     )
510 R(I,1) = (CK(I,2) - CK        (
     I,3)) / PS:R(I,2) = (        C
     K(I,4) - CK(I,3)) / P        S
     :R(I,3) = (CK(I + 1,3        )
      - CK(I,4)) / PS:R(I,        4
     ) = R(I,2) + R(I,3):R        (
     I,5) = (CK(I + 1,3) -
     CK(I + 1,1)) * VEL *         1
     00 / PS:R(I,6) = R(I,        4
     ) * VEL * 100
520 R(I,7) = 60 * PS / (CK        (
     I + 1,3) - CK(I + 1,1        )
     )
530  NEXT
540 L(NS,1) = (CK(NS - 1,4        )
      - CK(NS,1)) / PS:L(N        S
     ,2) = (CK(NS,2) - CK(        N
     S,1)) / PS:R(NS,1) =         (
     CK(NS,2) - CK(NS,3))         /
     PS:R(NS,2) = (CK(NS,4        )
      - CK(NS,3)) / PS
550  FOR I = 1 TO NS - 1
560  FOR J = 1 TO 3:L(I,3         *
     J + 5) = (D(I,2 * J -
     1) - CK(I,1)) * 100 /
     PS / L(I,4):L(I,3 * J         +
     6) = (D(I,2 * J) - CK        (
     I,1)) * 100 / PS / L(        I
     ,4):L(I,3 * J + 7) =         L
     (I,3 * J + 6) - L(I,3         *
     J + 5)
570 R(I,3 * J + 5) = (D(I,        2
      * J + 5) - CK(I,3))         *
     100 / PS / R(I,4):R(I        ,
     3 * J + 6) = (D(I,2 *
     J + 6) - CK(I,3)) * 1        0
     0 / PS / R(I,4):R(I,3         *
     J + 7) = R(I,3 * J +         6
     ) - R(I,3 * J + 5)
580  NEXT : NEXT
```

```
590  FOR I = 1 TO 2: FOR J         =
     1 TO 16:LM(I,J) = 0:R        M
     (I,J) = 0: NEXT : NEX        T

600  FOR I = 1 TO NS - 1:         FOR
     J = 3 TO 16:LM(1,J) =
     LM(1,J) + L(I,J) / (N        S
      - 1):RM(1,J) = RM(1,        J
     ) + R(I,J) / (NS - 1)        :
      NEXT : NEXT
610  IF NS <  = 2 GOTO 630
620  FOR I = 1 TO NS - 1:         FOR

     J = 3 TO 16:LM(2,J) =
     LM(2,J) + (L(I,J) - L        M
     (1,J)) ^ 2:RM(2,J) =         R
     M(2,J) + (R(I,J) - RM        (
     1,J)) ^ 2: NEXT : NEX        T

630  FOR I = 2 TO NS:LM(1,        1
     ) = LM(1,1) + L(I,1)         /
     (NS - 1): NEXT
640  IF NS <  = 2 GOTO 670
650  FOR I = 2 TO NS:LM(2,        1
     ) = LM(2,1) + (L(I,1)         -
     LM(1,1)) ^ 2: NEXT
660 LM(2,1) =  SQR (LM(2,1        )
      / (NS - 2))
670  FOR I = 1 TO NS:LM(1,        2
     ) = LM(1,2) + L(I,2)         /
     NS:RM(1,1) = RM(1,1)         +
     R(I,1) / NS:RM(1,2) =
     RM(1,2) + R(I,2) / NS        :
      NEXT
680  FOR I = 1 TO NS:LM(2,        2
     ) = LM(2,2) + (L(I,2)         -
     LM(1,2)) ^ 2:RM(2,1)         =
     RM(2,1) + (R(I,1) - R        M
     (1,1)) ^ 2:RM(2,2) =         R
     M(2,2) + (R(I,2) - RM        (
     1,2)) ^ 2: NEXT
690 LM(2,2) =  SQR (LM(2,2        )
      / (NS - 1)):RM(2,1)         =
      SQR (RM(2,1) / (NS -
     1)):RM(2,2) =  SQR (R        M
     (2,2) / (NS - 1))
700  IF NS <  = 2 GOTO 720
710  FOR I = 3 TO 16:LM(2,        I
     ) =  SQR (LM(2,I) / (        N
     S - 2)):RM(2,I) =  SQ        R
     (RM(2,I) / (NS - 1)):         NEXT

720  REM
730 OP = 1:D$ =  CHR$ (4)
740 M$ = F$
750  HOME : VTAB 10: FLASH
     : PRINT "STORING RESU        L
     TS - PLEASE WAIT !":         NORMAL
```

```
820  PRINT D$;"DELETE";M$
830  PRINT D$;"OPEN";M$
840  PRINT D$;"WRITE";M$
850  PRINT N$: PRINT S$: P       RINT
     AGE: PRINT WT: PRINT        H
     T: PRINT LL: PRINT RL       :
      PRINT LF: PRINT RF
860  PRINT P$: PRINT Y$: P       RINT
     VEL: PRINT X$: PRINT        D
     IST: PRINT TIME: PRIN       T
     PS: PRINT NS
870  FOR I = 1 TO NS: FOR        J
      = 1 TO 12: PRINT D(I       ,
     J): NEXT : NEXT
880  PRINT REL
890  FOR I = 1 TO 16: PRIN       T
     LM(1,I): NEXT : FOR I       =
     1 TO 16: PRINT RM(1,I       )
     : NEXT : FOR I = 1 TO
     16: PRINT LM(2,I): NE       XT



     : FOR I = 1 TO 16: PR       INT
     RM(2,I): NEXT
900  FOR I = 1 TO NS: FOR        J
      = 1 TO 16: PRINT L(I       ,
     J): NEXT : NEXT : FOR
     I = 1 TO NS: FOR J =        1
      TO 16: PRINT R(I,J):        NEXT
     : NEXT
910  PRINT D$;"CLOSE";M$
920  HOME : VTAB 8: PRINT        "
     RESULTS STORED": PRIN       T
     : INPUT "PRINT RESULT       S
      NOW (Y/N) ? ";F$: IF
     F$ = "N" GOTO 940
930  GOSUB 990
932  PRINT D$;"BLOAD CHAIN       ,
     D1,A520"
934  CALL 520"PLOT"
940  HOME : PRINT "THE RES       U
     LTS OF THIS ANALYSIS        A
     RE STORED IN FILE : "       ;
     M$
950  GOTO 50
990  HOME : FLASH : PRINT        "
     TURN PRINTER ON AND P       R
     ESS SPACE": GET C$: N       ORMAL
     : PRINT
1000  HOME : VTAB 12: FLAS       H
     : PRINT "PRINTING IN        P
     ROGRESS - PLEASE WAIT
     !": NORMAL
1010  PRINT D$;"PR#1"
1012  PRINT  CHR$ (9);"80N       "
```

```
1015  PRINT : PRINT : HTAB
     15: PRINT "DATA ANALY        S
     IS OF HEEL-BALL-TOE F        O
     OT CONTACT PATTERN":         HTAB
     15: PRINT "=========         =
     =====================        =
     ==================":         PRINT
     : PRINT
1020  PRINT "         FILE :
     ";M$
1022  PRINT "      SUBJECT :
     ";N$
1024  PRINT "          SEX :
     ";S$
1025  PRINT "          AGE :
     ";AGE
1026  PRINT "WEIGHT (KG) :
     ";WT
1028  PRINT "HEIGHT (KG) :
     ";HT
1030  PRINT : PRINT "  LEF        T
      LEG LENGTH (CM) : ";        L
     L
1032  PRINT " RIGHT LEG LE        N
     GTH (CM) : ";RL
1034  PRINT " LEFT FOOT LE        N
     GTH (CM) : ";LF
1036  PRINT "RIGHT FOOT LE        N
     GTH (CM) : ";RF: PRIN        T

1038  PRINT "
      PACE : ";P$

1040  PRINT "      VELOCITY
      (M/S) : "; INT (100 *
      VEL + 0.5) / 100
1042  PRINT "REL. SPEED (S        T
      AT/S) : "; INT (100 *
      REL + 0.5) / 100
1044  PRINT : PRINT
1060 Z$ = "LEFT LIMB":L =          LEN
      (Z$):S = INT ((84 -         L
      ) / 2 + 0.5): POKE 36       ,
      S: PRINT Z$: POKE 36,       S
      : FOR I = 1 TO L: PRI       NT
      "-";: NEXT : PRINT
1070  PRINT
1080  PRINT "STEP";: GOSUB
      1750: PRINT "NO.";: G       OSUB
      1770
1090  PRINT
1100  PRINT "L1";: POKE 36        ,
      10: PRINT "-----";: F       OR
      I = 2 TO 7: POKE 36,1       0
       * I: PRINT INT (100         *
      L(1,I) + 0.5) / 100;:        NEXT
      : PRINT
1110  FOR I = 2 TO NS - 1:         PRINT
      "L";I;: FOR J = 1 TO        7
      : POKE 36,10 * J: PRI       NT
```

```
      INT (100 * L(I,J) +        O
     .5) / 100;: NEXT : PR       INT
     : NEXT
1120  PRINT "L";NS;: FOR I        =
     1 TO 2: POKE 36,10 *        I
     : PRINT  INT (100 * L       (
     NS,I) + 0.5) / 100;:        NEXT
     : PRINT
1130  PRINT
1140  PRINT "MEAN";: FOR I        =
     1 TO 7: POKE 36,10 *        I
     : PRINT  INT (1000 *        L
     M(1,I) + 0.5) / 1000;       :
      NEXT : PRINT : PRINT
     "S.D.";: FOR I = 1 TO
     7: POKE 36,10 * I: PR       INT
      INT (1000 * LM(2,I)        +
     0.5) / 1000;: NEXT :        PRINT

1150  PRINT
1160  PRINT "  %";: POKE 3       6
     ,10: PRINT  INT (1000       O
      * LM(1,1) / LM(1,4)        +
     0.5) / 100;: POKE 36,       2
     O: PRINT  INT (10000        *
     LM(1,2) / LM(1,4) + O       .
     5) / 100;: POKE 36,30       :
      PRINT  INT (10000 *        L
     M(1,3) / LM(1,4) + O.       5
     ) / 100;: POKE 36,40:        PRINT
     "100";
1170  POKE 36,50: PRINT  I       NT
     (10000 * LM(1,5) / LM       (
     1,6) + 0.5) / 100;: P       OKE
     36,60: PRINT "100"
1180  PRINT : PRINT
1190 Z$ = "RIGHT LIMB":L =
      LEN (Z$):S =  INT ((       3
     4 - L) / 2 + 0.5): PO       KE
      36,S: PRINT Z$: POKE        3
      6,S: FOR I = 1 TO L:        PRINT
      "-";: NEXT : PRINT
 1200  PRINT : PRINT "STEP"       ;
      : GOSUB 1750: PRINT "       N
      O. ";: GOSUB 1770: PR       INT

 1210  FOR I = 1 TO NS - 1:        PRINT
      "R";I;: FOR J = 1 TO        7
      : POKE 36,10 * J: PRI       NT
       INT (100 * R(I,J) +        O
      .5) / 100;: NEXT : PR       INT
      : NEXT
 1220  PRINT "R";NS;: FOR I        =
      1 TO 2: POKE 36,10 *        I
      : PRINT  INT (100 * R       (
      NS,I) + 0.5) / 100;:        NEXT
      : PRINT
 1230  PRINT : PRINT "MEAN"       ;
      : FOR I = 1 TO 7: POK       E
      36,10 * I: PRINT  INT
      (1000 * RM(1,I) + 0.5       )
       / 1000;: NEXT : PRIN       T
```

```
1240  PRINT "S.D.";: FOR I       =
     1 TO 7: POKE 36,10 *       I
     : PRINT  INT (1000 *       R
     M(2,I) + 0.5) / 1000:      :
      NEXT : PRINT
1250  PRINT : PRINT "   %"      ;
     : POKE 36,10: PRINT        INT
     (10000 * RM(1,1) / RM      (
     1,4) + 0.5) / 100;: P      OKE
     36,20: PRINT  INT (10      O
     00 * RM(1,2) / RM(1,4      )
      + 0.5) / 100;: POKE       3
     6,30: PRINT  INT (100      O
     0 * RM(1,3) / RM(1,4)       +
     0.5) / 100;: POKE 36,      4
     0: PRINT "100";
1260  POKE 36,50: PRINT  I      NT
     (10000 * RM(1,5) / RM      (
     1,6) + 0.5) / 100;: P      OKE
     36,60: PRINT "100"
1270  GOSUB 2130
1280  PRINT : PRINT
1290 Z$ = "LEFT FOOT":L =        LEN
     (Z$):S =  INT ((84 -       L
     ) / 2 + 0.5): POKE 36      ,
     S: PRINT Z$: POKE 36,      S
     : FOR I = 1 TO L: PRI      NT
     "-";: NEXT : PRINT
1300  PRINT : GOSUB 1780:       PRINT
     : FOR I = 1 TO NS - 1      :
      PRINT "L";I;: FOR J        =
     8 TO 16 STEP 3: FOR K       =
     1 TO 3: POKE 36,8 * (      J
      - 7) + (K - 1) * 7:J      J
      = J + K - 1: PRINT        INT
     (100 * L(I,JJ) + 0.5)       /
     100;: NEXT : NEXT : P      RINT
     : NEXT
1310  PRINT : PRINT "MEAN"      ;
     : FOR I = 8 TO 16 STE      P
     3: FOR J = 1 TO 3: PO      KE
     36,8 * (I - 7) + (J -
     1) * 7:II = I + J - 1      :
      PRINT  INT (1000 * L      M
     (1,II) + 0.5) / 1000:      :
      NEXT : NEXT : PRINT
1320  PRINT "S.D.";: FOR I       =
     8 TO 16 STEP 3: FOR J       =
     1 TO 3: POKE 36,8 * (      I
      - 7) + (J - 1) * 7:I      I
      = I + J - 1: PRINT        INT
     (LM(2,II) + 0.5) / 10      O
     0;: NEXT : NEXT : PRI      NT

1330  PRINT : PRINT
1340 Z$ = "RIGHT FOOT":L =
      LEN (Z$):S =  INT ((      8
     4 - L) / 2 + 0.5): PO      KE
     36,S: PRINT Z$: POKE       3
     6,S: FOR I = 1 TO L:       PRINT
```

```
     "-";: NEXT : PRINT
1350  PRINT : GOSUB 1780:       PRINT
     : FOR I = 1 TO NS - 1       :
      PRINT "R";I;: FOR J       =
     8 TO 16 STEP 3: FOR K       =
     1 TO 3: POKE 36,8 * (     J
      - 7) + (K - 1) * 7:J     J
      = J + K - 1: PRINT        INT
     (100 * R(I,JJ) + 0.5)       /
     100;: NEXT : NEXT : P      RINT
     : NEXT
1360  PRINT : PRINT "MEAN"      ;
     : FOR I = 8 TO 16 STE      P
     3: FOR J = 1 TO 3: PO      KE
     36,8 * (I - 7) + (J -
     1) * 7:II = I + J - 1      :
      PRINT  INT (1000 * R      M
     (1,II) + 0.5) / 1000;      :
      NEXT : NEXT : PRINT
1370  PRINT "S.D.";: FOR I       =
     8 TO 16 STEP 3: FOR J       =
     1 TO 3: POKE 36,8 * (     I
      - 7) + (J - 1) * 7:I     I
      = I + J - 1: PRINT        INT
     (RM(2,II) + 0.5) / 10      0
     0;: NEXT : NEXT : PRI      NT

1380  PRINT : PRINT : PRIN      T

1390 Z$ = "LEFT CONTACT PA      T
     TERN":ST = LM(1,4):SP       =
     LM(1,2):Z1 = LM(1,8):      Z
     2 = LM(1,10):Z3 = LM(      1
     ,11):Z4 = LM(1,13):Z5       =
     LM(1,14):Z6 = LM(1,16      )
     : GOSUB 1440
1400  PRINT : PRINT
1410 Z$ = "RIGHT CONTACT P      A
     TTERN":ST = RM(1,4):S      P
      = RM(1,2):Z1 = RM(1,      8
     ):Z2 = RM(1,10):Z3 =       R
     M(1,11):Z4 = RM(1,13)      :
     Z5 = RM(1,14):Z6 = RM      (
     1,16): GOSUB 1440
1420  PRINT : PRINT : PRIN      T
     : PRINT
1430  PRINT D$;"PR#0": RET      URN
1440 Z1 =  INT (Z1 * ST /       S
     P / 2 + 0.5)
1450 Z2 =  INT (Z2 * ST /       S
     P / 2 + 0.5)
1460 Z3 =  INT (Z3 * ST /       S
     P / 2 + 0.5)
1470 Z4 =  INT (Z4 * ST /       S
     P / 2 + 0.5)
1480 Z5 =  INT (Z5 * ST /       S
     P / 2 + 0.5)
1490 Z6 = 70 - (Z5 + 20)
1500  POKE 36,10: FOR I =       1
```

```
      TO 6: PRINT ".";: NE      XT
     : PRINT
1510  POKE 36,9: PRINT ":       T
     OE  :";: POKE 36,Z5 +
     20: FOR I = 1 TO Z6:       PRINT
     "*";: NEXT : POKE 36,      7
     0: PRINT "+100"
1520  POKE 36,8: PRINT ":"      ;
     : POKE 36,17: PRINT "      :
     ";: POKE 36,Z5 + 20:       FOR
     I = 1 TO Z6: PRINT "*      "
     ;: NEXT : POKE 36,70:       PRINT
     "I"
1530  POKE 36,7: PRINT ":"      ;
     : POKE 36,18: PRINT "      :
     ";: POKE 36,70: PRINT
     "I": POKE 36,6: PRINT
     ":";: POKE 36,19: PRI      NT
     ":";: POKE 36,70: PRI      NT
     "I": POKE 36,6: PRINT
     ":";: POKE 36,19: PRI      NT
     ":";: POKE 36,70: PRI      NT
     "I    F"
1540  POKE 36,7: PRINT ":"      ;
     : POKE 36,18: PRINT "      :
     ";: POKE 36,70: PRINT
     "+ 75 O"
1550  POKE 36,7: PRINT ":
      BALL    :";
1560  POKE 36,Z3 + 20: FOR
     I = 1 TO Z4: PRINT "*      "
     ;: NEXT
1570  POKE 36,70: PRINT "I
        O"
1580  POKE 36,7: PRINT ":
               :";
1590  POKE 36,Z3 + 20: FOR
     I = 1 TO Z4: PRINT "*      "
     ;: NEXT
1600  POKE 36,70: PRINT "I
        T"
1610  POKE 36,7: PRINT ":"      ;
     : POKE 36,18: PRINT "      :
     ";: POKE 36,70: PRINT
     "I": POKE 36,8: PRINT
     ":";: POKE 36,17: PRI      NT
     ":";: POKE 36,70: PRI      NT
     "I": POKE 36,8: PRINT
     ":";: POKE 36,17: PRI      NT
     ":";
1620  POKE 36,70: PRINT "+
     50 L"
1630  POKE 36,9: PRINT ":"      ;
     : POKE 36,16: PRINT "      :
     ";: POKE 36,35: PRINT
     Z$;
1640  POKE 36,70: PRINT "I
        E"
1650  POKE 36,9: PRINT ":"      ;
     : POKE 36,16: PRINT "      :
```

```
     ":
1660  POKE 36,70: PRINT "I
        N"
1670  POKE 36,9: PRINT ":"      ;
     : POKE 36,16: PRINT "      :
     ";: POKE 36,70: PRINT
     "I    G": POKE 36,8:       FOR
     I = 1 TO 10: PRINT ".      "
     ;: NEXT : POKE 36,70:       PRINT
     "I    T"
1680  POKE 36,8: PRINT ":"      ;
     : POKE 36,17: PRINT "      :
     ";: POKE 36,70: PRINT
     "+ 25 H": POKE 36,8:       PRINT
     ":";: POKE 36,17: PRI      NT
     ":";: POKE 36,70: PRI      NT
     "I"
1690  POKE 36,8: PRINT ":"      ;
     : POKE 36,17: PRINT "      :
     ";: POKE 36,70: PRINT
     "I    %": POKE 36,8:       PRINT
     ":  HEEL  :";: POKE 3      6
     ,Z1 + 20: FOR I = 1 T      O
     Z2: PRINT "*";: NEXT       :
      POKE 36,70: PRINT "I      "

1700  POKE 36,9: PRINT ":"      ;
     : POKE 36,16: PRINT "      :
     ";: POKE 36,Z1 + 20:       FOR
     I = 1 TO Z2: PRINT "*      "
     ;: NEXT : POKE 36,70:       PRINT
     "I"
1710  POKE 36,9: PRINT ":.      .
     ....:";: POKE 36,20:       PRINT
     "+";: FOR I = 1 TO 10      :
      FOR J = 1 TO 4: PRIN      T
     "-";: NEXT : PRINT "+      "
     ;: NEXT : PRINT "  0"
1720  FOR I = 1 TO 11: POK      E
     36,(I - 1) * 5 + 20:       PRINT
     (I - 1) * 10;: NEXT :       PRINT

1730  POKE 36,35: PRINT "S      U
     PPORT TIME (%)"
1740  RETURN
1750  POKE 36,70: PRINT "'      I
     NST.'"
1760  POKE 36,10: PRINT "B      D
     S";: POKE 36,20: PRIN      T
     "SUPPORT";: POKE 36,3      0
     : PRINT "SWING";: POK      E
     36,40: PRINT "STRIDE"      ;
     : POKE 36,50: PRINT "      S
     TEP";: POKE 36,60: PR      INT
     "STRIDE";: POKE 36,70      :
      PRINT "CADENCE,": RE      TURN

1770  POKE 36,10: PRINT "T      I
     ME, S";: POKE 36,20:       PRINT
     "TIME, S";: POKE 36,3      0
```

```
      : PRINT "TIME, S";: P      OKE
      36,40: PRINT "TIME, S      "
      ;: POKE 36,50: PRINT       "
      LEN, CM";: POKE 36,60      :
       PRINT "LEN, CM";: PO      KE
      36,70: PRINT "STEPS/M      I
      N": RETURN
1780   POKE 36,14: PRINT "H      E
      EL";: POKE 36,38: PRI      NT
      "BALL";: POKE 36,62:       PRINT
      "TOE"
1790   PRINT : PRINT "STEP"      ;
      : POKE 36,8: PRINT "O      N
      ";: POKE 36,15: PRINT
      "OFF";: POKE 36,22: P      RINT
      "TOTAL";: POKE 36,32:       PRINT
      "ON";: POKE 36,39: PR      INT
      "OFF";: POKE 36,46: P      RINT
      "TOTAL";
1800   POKE 36,56: PRINT "O      N
      ";: POKE 36,63: PRINT
      "OFF";: POKE 36,70: P      RINT
      "TOTAL"
1810   POKE 36,20: PRINT "(
      P E R C E N T   O F
      S T R I D E   T I M E
      )": RETURN
1820   HOME : PRINT : INVER      SE
      : PRINT "PRINT STORED
      RESULTS :": NORMAL
1830   VTAB 8: PRINT "ENTER
      NAME OF FILE CONTAINI      N
      G RESULTS   TO BE PRI      N
      TED"
1840   PRINT : INPUT "FILEN      A
      ME: ";M$: IF  LEN (M$      )
       > 29 THEN  PRINT : I      NVERSE
      : PRINT "ERROR IN FIL      E
      NAME - PLEASE RE-ENTE      R
      ": NORMAL : GOTO 1840
1850  OP = 2
1860  D$ =  CHR$ (4)
1870   VTAB 14: PRINT "INSE      R
      T DATA DISK INTO DRIV      E
       #2": PRINT "THEN PRE      S
      S A KEY ";: GET F$: P      RINT

1880  TP = 7: GOSUB 2000: V      TAB
      8: PRINT "RETRIEVING:
      ";M$
1890   PRINT D$;"OPEN";M$;"      ,
      D2": PRINT D$;"READ";      M
      $
1900   INPUT N$: INPUT S$:       INPUT
      AGE: INPUT WT: INPUT       H
      T: INPUT LL: INPUT RL      :
       INPUT LF: INPUT RF
1910   INPUT P$: INPUT Y$:       INPUT
      VEL: INPUT X$: INPUT       D
```

```
      IST: INPUT TIME: INPU      T
      PS: INPUT NS
 1920  FOR I = 1 TO NS: FOR
      J = 1 TO 12: INPUT D(      I
      ,J): NEXT : NEXT
 1930  INPUT REL
 1940  FOR I = 1 TO 16: INP      UT


      LM(1,I): NEXT : FOR I       =
      1 TO 16: INPUT RM(1,I      )
      : NEXT : FOR I = 1 TO
      16: INPUT LM(2,I): NE      XT
      : FOR I = 1 TO 16: IN      PUT
      RM(2,I): NEXT
 1950  FOR I = 1 TO NS: FOR
      J = 1 TO 16: INPUT L(      I
      ,J): NEXT : NEXT : FO      R
      I = 1 TO NS: FOR J =       1
       TO 16: INPUT R(I,J):       NEXT
      : NEXT
 1960  PRINT D$;"CLOSE";M$
 1970 TP = 3: GOSUB 2000: V      TAB
      8: PRINT "DATA RETRIE      V
      ED": PRINT : INPUT "P      R
      INT RESULTS NOW (Y/N)
      ? ";F$: IF F$ = "N" G      OTO
      40
 1980  GOSUB 990
 1985  PRINT D$;"BLOAD CHAI      N
      ,D1,A520"
 1990  CALL 520"PLOT"
 2000  POKE 34,TP: HOME : P      OKE
      34,0: RETURN
 2010 Y =  PEEK (222)
 2020  IF Y = 5 GOTO 2060
 2030  IF Y = 6 GOTO 2100
 2040  IF Y = 9 GOTO 2110
 2050  GOTO 2120
 2060  IF OP = 2 GOTO 2080
 2070  PRINT D$;"DELETE";M$      :
       GOTO 830
 2080  HOME : VTAB 8: PRINT
      "FILE NOT FOUND": PRI      NT
      D$;"DELETE";M$: PRINT
      : INPUT "IS FILE NAME
      CORRECT (Y/N) ? ";F$:       IF
      F$ = "N" GOTO 1820
 2090  PRINT : PRINT "INSER      T
       CORRECT DATA DISK IN      T
      O DRIVE #2": PRINT "T      H
      EN PRESS A KEY ";: GE      T
      F$: PRINT : GOTO 1850
 2100  HOME : VTAB 10: PRIN      T
      "PROGRAM NOT FOUND":       PRINT
      : PRINT "INSERT CORRE      C
      T PROGRAM DISK INTO D      R
      IVE#1": PRINT "THEN P      R
      ESS A KEY ";: GET F$:       PRINT
      : GOTO 6040
 2110  HOME : VTAB 10: PRIN      T
      "DISK FULL": PRINT :       PRINT
```

```
      "INSERT ANOTHER INITI      A
      LIZED DISK INTO ": PR      INT
      "DRIVE #2 THEN PRESS       A
       KEY ";: GET F$: PRIN      T
      : GOTO 750
2120   POKE 216,0: RESUME
2130   REM  - SUBROUTINE TO
      PRINT SUMMARY DATA
2140   PRINT : PRINT : PRIN      T

2150   POKE 36,21: PRINT "S      U
      MMARY DATA": POKE 36,      2
      1: PRINT "===========      =


      ": PRINT : PRINT
2160   POKE 36,11: PRINT "S      D
      S";: POKE 36,21: PRIN      T
      "SUPPORT";: POKE 36,3      1
      : PRINT "SWING";: POK      E
      36,41: PRINT "STEP";:       POKE
      36,51: PRINT "TDS"
2170   POKE 36,11: PRINT "T      I
      ME, S";: POKE 36,21:       PRINT
      "TIME, S";: POKE 36,3      1
      : PRINT "TIME, S";: P      OKE
      36,41: PRINT "LEN, CM      "
      ;: POKE 36,51: PRINT       "
      TIME, S"
2180   PRINT : PRINT
2190   PRINT " LT. MEAN";:       FOR
      I = 1 TO 3: POKE 36,1      0
       * I + 1: PRINT  INT       (
      1000 * LM(1,I) + 0.5)       /
      1000;: NEXT
2200   POKE 36,41: PRINT  I      NT
      (1000 * LM(1,5) + 0.5      )
       / 1000;: POKE 36,51:       PRINT
       INT (1000 * RM(1,1)       +
      0.5) / 1000
2210   POKE 36,5: PRINT "S.      D
      .";: FOR I = 1 TO 3:       POKE
      36,10 * I + 1: PRINT        INT
      (1000 * LM(2,I) + 0.5      )
       / 1000;: NEXT
2220   POKE 36,41: PRINT  I      NT
      (1000 * LM(2,5) + 0.5      )
       / 1000;: POKE 36,51:       PRINT
       INT (1000 * RM(2,1)       +
      0.5) / 1000
2230   PRINT : POKE 36,6: P      RINT
      "%";: POKE 36,11: PRI      NT
       INT (10000 * LM(1,1)       /
      LM(1,4) + 0.5) / 100;      :
       POKE 36,21: PRINT 10      0
       -  INT (10000 * LM(1      ,
      3) / LM(1,4) + 0.5) /
      100;: POKE 36,31: PRI      NT
       INT (10000 * LM(1,3)       /
      LM(1,4) + 0.5) / 100;
2240   POKE 36,41: PRINT  I      NT
```

```
      (10000 * LM(1,5) / LM        (
      1,6) + 0.5) / 100;: P        OKE
      36,51: PRINT  INT (10        0
      00 * RM(1,1) / RM(1,4        )
       + 0.5) / 100
2250   PRINT : PRINT " RT.         M
      EAN";: FOR I = 1 TO 3        :
       POKE 36,10 * I + 1:         PRINT
       INT (1000 * RM(1,I)         +
      0.5) / 1000;: NEXT
2260   POKE 36,41: PRINT  I        NT
      (1000 * RM(1,5) + 0.5        )
       / 1000;: POKE 36,51:         PRINT
       INT (1000 * LM(1,1)         +
      0.5) / 1000
2270   POKE 36,5: PRINT "S.        D
      .";: FOR I = 1 TO 3:         POKE
      36,10 * I + 1: PRINT          INT
      (1000 * RM(2,I) + 0.5        )
       / 1000;: NEXT


2280   POKE 36,41: PRINT  I        NT
      (1000 * RM(2,5) + 0.5        )
       / 1000;: POKE 36,51:         PRINT
       INT (1000 * LM(2,1)         +
      0.5) / 1000
2290   PRINT : POKE 36,6: P        RINT
      "%";: POKE 36,11: PRI        NT
       INT (10000 * RM(1,1)         /
      RM(1,4) + 0.5) / 100;        :
       POKE 36,21: PRINT 10        0
       -  INT (10000 * RM(1        ,
      3) / RM(1,4) + 0.5) /
      100;: POKE 36,31: PRI        NT
       INT (10000 * RM(1,3)         /
      RM(1,4) + 0.5) / 100;
2300   POKE 36,41: PRINT  I        NT
      (10000 * RM(1,5) / RM        (
      1,6) + 0.5) / 100;: P        OKE
      36,51: PRINT  INT (10        0
      00 * LM(1,1) / LM(1,4        )
       + 0.5) / 100
2310   PRINT : PRINT
2320   POKE 36,11: PRINT "S        T
      RIDE";: POKE 36,21: P        RINT
      "STRIDE";: POKE 36,31        :
       PRINT "CADENCE"
2330   POKE 36,11: PRINT "T        I
      ME, S";: POKE 36,21:         PRINT
      "LEN, CM";: POKE 36,3        1
      : PRINT "STEPS/MIN"
2390   PRINT : PRINT
2400   POKE 36,4: PRINT "ME        A
      N";: POKE 36,11: PRIN        T
       INT (1000 * LM(1,4)         +
      0.5) / 1000;: POKE 36        ,
```

```
      21: PRINT  INT (1000         *
      LM(1,6) + 0.5) / 1000        ;
      : POKE 36,31: PRINT          INT
      (120000 / LM(1,4) + 0        .
      5) / 1000
2410   POKE 36,5: PRINT "S.        D
      .";: POKE 36,11: PRIN        T
       INT (1000 * LM(2,4)         +
      0.5) / 1000;: POKE 36        ,
      21: PRINT  INT (1000         *
      LM(2,6) + 0.5) / 1000
2420   PRINT
2430   POKE 36,6: PRINT "%"        ;
      : POKE 36,11: PRINT "        1
      00";: POKE 36,21: PRI        NT
      "100"
2440   RETURN
```