An Ergonomics Evaluation of the Load on the Spine During Distance Running and Circuit Weight-training.

by

Gerard Garbutt.

BSc(Hons).,MSc.,MIBIOL,CBIOL.,M.Erg.S

A thesis submitted for the award of the degree of Doctor of Philosophy

December, 1992. Liverpool John Moores University

"By reason of the frailty of our nature we cannot always stand upright"

Book of Common Prayer.

Acknowledgements

I am indebted to Professor Thomas Reilly, my supervisor, for his continuous support throughout the development of this thesis. His enthusiasm, support and wise counsel have always been given generously. His contribution to my professional and personal development cannot be underestimated. For this I will always be grateful.

I wish to thank Dr.J.D.G.Troup MD DSc (Med) for his astute, incisive and constructive criticism of my work, which has focused the mind and been invaluable in the preparation of the thesis.

Thanks are due to the Health Promotion Research Trust for providing the financial support for my research.

A special word of thanks is reserved for my wife, Sue, for her continued love, patience, tolerance and assistance. And to my children Emma and George who have been a more than welcome distraction!

I dedicate this thesis to the memory of my loving mother Elizabeth, whom to my eternal regret did not live to see its completion. And to my father Frank, who provided the art-work for this thesis and inspired me to achieve.

ABSTRACT

This thesis adopted an ergonomics approach to the study of low-back pain in distance running and circuit weight-training (CWT). Rates of low-back pain were determined using epidemiological techniques and likely aetiological factors were investigated. Spinal loading was evaluated using changes in stature. Physiological and perceived stresses in response to each exercise mode were monitored. Spinal mobilisation procedures, pre- and post-exercise, were evaluated to determine their usefulness in attenuating loading.

In distance runners the rates of lower back injury and low-back pain were between 21-39%. Training variables were not significantly associated with injury ($p>0.05$). In weight-trainers the prevalence of lower-back pain was 13%.

An increase in running speed was found to enhance stature loss (shrinkage) ($p<0.005$), which was greater during the early stage of the run ($p<0.05$) and independent of low-back pain ($p>0.05$). During a simulated marathon, runners failed to reproduce their competition performance: methodological difficulties led to stature loss being underestimated. The CWT caused similar shrinkage to that found in running, but provided a less effective aerobic training stimulus.

Spinal mobilisation exercises had no significant effect on change in stature ($p>0.05$). In four separate conditions change in stature was inversely related to lower back and hip flexibility ($r=-0.77$ to -0.84; $p<0.05$).

Spinal loading in CWT does not appear excessive when compared with running, but CWT engages anaerobic as well as aerobic mechanisms. Therefore exercise intensity in CWT may not guarantee sufficient stimulation for aerobic training. Spinal loading in exercise may be attenuated in more flexible athletes. The long term effects of improvements in flexibility for back pain prevention should be further explored.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

INTRODUCTION

1.1 THE PROBLEM OF LOW-BACK PAIN

Low-back pain reportedly affects up to 80% of the adult population (White and Gordon, 1982a). Waddell (1982) claimed that at least one in every two people in industrial societies suffers from back pain at some time in their life. In a survey of residents in a Copenhagen suburb, in which 82% of the population were sampled, Biering-Sorensen (1982) found the cumulative lifetime prevalence of low-back pain to be 62%. The point prevalence (those reporting low-back pain at the time of the survey) was 14% and the subsequent one year prevalence 45%. Not only is there a high prevalence of low-back pain in society, but the recurrence rate is also high. Troup et al. (1981) found that 49% of people presenting with low-back pain would have a further episode within 12 months and 32% within 24 months. These findings were supported by Biering-Sorensen (1983) who found a 64% recurrence rate over 12 months. Consequently back pain is a common cause of morbidity, disability and threat to health.

The Health and Safety Executive's statistics, cited by Troup and Edwards (1985), showed that the lower back was more commonly affected by occupational over-exertion than other parts of the body, accounting for 61% of the total injuries. The DHSS data for 1977-78 relating to periods of certified incapacity in workers showed that there were 78,000 periods of certification for men and 10,000 for women resulting from lower back sprains and strains. The median duration of disability was 13-14 days. Data for 1980 showed that 16% of the 15.3 million days lost through industrial injury were due to sprains and strains of the back. Troup and Edwards (1985) stated that 1 to 2% of the population of Great Britain were certified as incapacitated due to low-back pain each year. This number, and the consequent loss of 20 million working days, was likely to be an underestimation of the extent of the problem, as the statistics could not account for unrecorded cases and restricted work capacity.

Gillanders in a personal communication (Health and Safety Executive, Newcastle, April, 1992) stated that 13% of certified sickness was due to back pain, and the estimated number of working days lost was between 52 - 60 million days, for 1989-90. The economic cost of this to the U.K was put at around four billion pounds. Such statistics demonstrate that low-back pain is a problem of massive magnitude in industry. However, the low-back pain problem is not restricted to the work environment.

The social, occupational and economic implications of chronic low-back pain on society have been well documented. White and Gordon (1982) suggested that low-back pain has damaging and wide ranging effects on personality and emotional well-being, which could lead to depression, anxiety, and fear about health status. This implied that low-back pain had wider consequences for the sufferer than the purely physical. Low-back pain affects social well-being and hence permeates through the sufferer's lifestyle (Poussaint, 1980; White and Gordon, 1982). The consequences of low-back pain extend through work, sport and leisure activities.

Epidemiological and clinical case series reports on orthopaedic problems among sports participants indicate that around 10% of injuries are to the lower back (Ovara and Puranen, 1978; Lutter, 1980; Devereaux and Lachmann, 1983). It has been found that low-back pain among athletes may prevent or limit ability to participate in exercise for a prolonged period (Cannon and James, 1984).

This thesis will use an ergonomics approach to examine the relationships between spinal loading and low-back pain during aerobic exercise regimens, specifically distance running and circuit weight-training (CWT). The incidence of low-back injury and associated aetiological factors, in runners and weight-trainers, will be determined using epidemiological techniques. The spinal, physiological and perceptual stresses imposed by distance running and CWT will be also be evaluated to determine the stress imposed. This should allow recommendations to be made as to the benefits and limitations of each exercise with respect to spinal loading. The potential of adopting exercises which unload the spine into an exercise regimen will also be assessed. Spinal loading will be assessed using measures of change in stature.

1.2 CLASSIFICATION OF SPINAL INJURY AND IDIOPATHIC LOW-BACK PAIN

Troup (1981) employed a three tier classification system for spinal injury. Firstly, non-bony injury with the spine remaining stable; secondly, injury causing instability and potential spinal cord or nerve root damage; thirdly, injury causing "gross neurological damage and imminent deformity". Most back injuries in sport fall into the first category.

Troup (1981) maintained that the ability of the spine to withstand considerable compressive, tensile, shearing and torsional forces is due to intervertebral movement and the plasticity of the components of the spinal column. The capacity of the spine to resist injury is decreased if the forces applied involve flexion and are of long duration (Adams and Hutton, 1982). Spinal strength has been shown to be inversely proportional to the duration of load application (Perey, 1957; Roaf, 1960; Holdsworth, 1970). Factors which increase the probability of lower back injury include prolonged static loading, vibratory stress, repetitive impacts and shocks (Troup, 1981). Such stresses are unavoidable in many sporting activities. Back injury may result if the forces on the spine during exercise are excessive.

Individual variation in response to spinal loading also affects the risk of injury. The ability of spinal structures to deform and reform is limited according to age, freedom from disease or degeneration and the size and direction of the load applied (Taylor and Twomey, 1980; Adams and Hutton, 1982; Twomey and Taylor, 1982). The capability of the individual to withstand spinal stresses also varies according to: the size and physical characteristics of the spinal column; to muscular strength; to skill and experience in task performance; and to the presence of absence of degenerative changes or abnormalities.

It is often difficult to identify the specific action or mechanism which is the cause of the injury, because the facets of the apophyseal joints and the nuclei of the intervertebral discs do not have a nerve supply (Troup, 1981). Neurological inhibitory mechanisms may prevent painful sensations being conveyed to the higher centres of the brain. For these reasons pain onset may be delayed. This can often lead to difficulty in the diagnosis of the damage to the structures of the back and the cause of pain, despite thorough clinical evaluation of the patient.

No simple cause and effect relationship has been established between a particular aetiology and chronic low-back pain. In a series of cases of low-back pain presented at a clinic, Kersely (1979) found that a definite diagnosis was possible in only 19.4% of cases (11% were disc lesions). Almost 81% of cases were given no definite diagnosis. Such findings have lead to the term idiopathic low-back pain, in reference to the high proportion of cases of the syndrome when no diagnosis is possible (White and Gordon, 1982). Pheasant (1991) suggested that the diagnosis may not be essential, from an ergonomics perspective, as preventative interventions to reduce the risk of low-back trouble would probably be similar regardless of the specific pathology.

Most personal risk factors (Table 1) generally have low predictive value of susceptibility to lower-back problems. A cumulative trauma model for the aetiology of lower-back injury suggests that low-back pain is a product of environmental and personal risk factors (Pheasant, 1991). Support for the cumulative trauma model comes from Kumar (1991) who found that the cumulative compressive loads at the thoracolumbar and lumbosacral discs, were greater for nurse aides with low-back pain compared to those without. The cumulative loading was determined by biomechanical modelling, derived from limited anthropometric data. The work tasks were simulated from descriptions of the nurse aides activities acted out by the aides, or simulated using a 3-D manikin, which was then transcribed in 2-D. The time course of loading was derived from a questionnaire relating to employment activity. Analysis of loads by means of biomechanical modelling from video or film, using actual anthropometric data could provide a more accurate estimation of cumulative load.

Table 1. Personal risk factors associated with low-back pain.

Strong Risk Factors
- Previous history of low-back pain
- Low overall fitness
- Low lifting strength - combined with task demand
- Low endurance of back muscles
- Smoking
- Motherhood

Moderate risk factors (may be significant in extreme cases, or in heavy work)
- Hypermobility
- Spondylolysis
- Spondylolysthesis
- Scoliosis and unequal leg length
- Weak back muscles, weak abdominal muscles
- Tight hamstrings (Predict recurrence but not first attack)

Weak or very weak risk factors
- Stature
- Overweight

No predictive value
- Lordosis or flat back
- Abnormal vertebral number
- Spina bifida occulta

Adapted from Pheasant, (1991).

An important objective of an ergonomics investigation into injury and human physical activity is to determine the risk currently associated with the activity.

Associated aetiological factors whether of genetic or environmental origin should also be determined. It may then be possible to alter human behaviour or the environment in which the behaviour takes place to reduce the risk of injury from the activity.

1.3 AN ERGONOMICS APPROACH TO THE LOWER BACK PROBLEM IN SPORT

The potential benefits of adopting a ergonomics approach to the study of sport were recognised by Reilly (1975) who wrote:

> "A satisfactory perspective from which to study the problems of stress is provided by ergonomics. This embodies an interdisciplinary approach to the study of the human operator in his interaction with his work and working environment. It embraces the human sciences, utilises physiological, psychological and anthropometric research while devising unique evaluative techniques to solve problems. It focuses on problems and fundamental principles of human performance."

Epidemiological, biological and psychological techniques have been used widely in low-back pain research in industrial contexts in order to reduce the cost of the low-back pain problem in industry (Troup and Edwards, 1985; Pheasant, 1991). An ergonomics approach has been employed, particularly in high risk industries, in assessing the load on the spine and in screening for individuals at risk from lower back injury. Methods employed include pre-employment strength testing to select workers, improved job design and the adoption of training procedures (Chaffin et al., 1978; Westgaard and Arras, 1985; Videman et al., 1989). Videman et al. (1989) have shown that a training programme adopting ergonomics and biomechanics principles could improve the patient handling skills of student nurses. Nurses found to have poor or bad patient handling skills were also at greater risk of lower back injury than their more highly skilled colleagues.

An analogous situation to that found in industry arises in sport and exercise. Williams (1980) stated that injury in sports and exercise was the result of specific mechanisms which overload part or all of the body. The overload in sport which causes lower back injury may result from poor technique or inappropriate training regimens. Identification of the training mechanisms overloading the lower back and causing injury, using a multi-disciplinary approach, may provide information which could be used to reduce the load on the spine. Subsequently, alterations to exercise programmes could be made to attenuate spinal loading, thereby reducing the risk of low-back injury. The success of this approach was demonstrated in nurse training (Videman et al., 1989). The adoption of an ergonomics approach to the study of low-back pain in sports and exercise may offer the greatest hope for future improvement in reducing the injury problem.

In recent years, positive health benefits have been shown to result from regular participation in aerobic exercise (Macleod et al., 1987). Two forms of exercise used to promote aerobic improvements are running and circuit weight-training (CWT). Either can overload the body and result in maladaptations such as musculo-skeletal symptoms or injury. Each has been associated with a high prevalence of low-back pain among participants (Basford, 1985; Powell et al., 1986). If the mechanisms of overload during these activities could be identified then a means of reducing spinal loading could be developed.

White and Gordon (1982) saw a need for the measurement of the load on the spine during occupational and leisure activities during which the spinal structures are loaded. This could provide information on the relations between such activities and the load imposed on the spine. Alexander (1985) maintained that when more progress had been made in determining the magnitude and direction of forces which cause lower back trauma, it may be possible to avoid injury by evading or reducing the forces.

Alexander (1985) also emphasized the disadvantage of using analysis "in vitro". Muscle, tendons and ligaments surround the vertebral body "in vivo" which may cause the anatomical structures such as the intervertebral disc to behave differently to responses observed on cadavers. The tolerance of these combined structures to loading may be substantially higher than current stress tolerance data would suggest. In this respect a technique for assessing spinal loading by measuring spinal shrinkage in vivo, in response to loading, may have the advantage of giving an accurate representation of the response of the whole spine to stress.

The load on the spine during exercise and occupational activities has been related to spinal shrinkage, using recently developed apparatus (Reilly et al., 1984; Eklund and Corlett, 1987). Such changes are proportional to lumbosacral compression, perception of exertion and levels of postural discomfort (Troup et al., 1985; Corlett et al., 1987).

The use of spinal shrinkage to assess loading could have important implications as part of an ergonomics assessment of the load on the spine during aerobic exercise. Identification of harmful mechanisms which excessively load the spine during exercise would allow their reduction or elimination. Pre- and post-exercise procedures, normally used by athletes as part of a warm-up or warm-down regimen, could also be evaluated to determine whether they attenuate or reverse spinal loading. Following assessment of the effects of running and CWT, it may be possible to alter the design of training regimens in order to reduce overloading of the lower back thereby reducing the risk of injury.

This study aims to evaluate the responses to the loads imposed on the body during distance running and CWT using an ergonomics approach. Epidemiological techniques will be used to identify the prevalence and incidence of low-back pain among participants in these activities. Physiological measurements and perceptual scaling techniques, already applied successfully in industrial contexts, will be used to monitor the strains placed on the individual during these activities. The relationship between spinal shrinkage and physiological and perceptual responses to exercise will be examined. Regimens designed to unload the spine post-exercise or attenuate shrinkage during exercise will also be evaluated. The relationship between spinal shrinkage and loading in chronic low-back pain sufferers and asymptomatic individuals will also be established. The ergonomics approach proposed by Reilly (1975) can be adopted for the assessment of stress during running and CWT. The responses to loading are manifest in physical, physiological and perceptual alterations and require multi-disciplinary assessment of stress.

1.4 EPIDEMIOLOGY

Epidemiology is the branch of science concerned with the occurrence, transmission and control of epidemic diseases. Epidemiological studies can provide information on the distribution and cause of a condition in a population. Data from such studies help in planning the prevention and cure of the condition. Epidemiology relies upon the attribution of a causal mechanism, or mechanisms, to a particular disease. Once cause has been established a prevention or cure can be evaluated scientifically.

The rate of occurrence of an injury is the fundamental concept of sports and exercise epidemiology (Clements et al., 1981; Powell et al., 1986; Hoeberigs, 1992). Rate of injury can be defined as the number of persons with an injury (the numerator), divided by the population at risk of injury (the denominator). The incidence rate is the number of new injuries occurring during an observation period, usually 12 months. The prevalence of a condition refers to the total number of injuries obtaining over a specified period of time, including existing conditions and those newly occurring (Powell et al., 1986; Hoeberigs, 1992).

In this thesis the occurrence of low-back pain and lower back injury will be expressed as follows:-

1) The prevalence of low-back pain refers to the percentage of people suffering from the complaint in a sample of a population over a period of time and includes existing and new occurrences. In particular the period prevalence of 12 months prior to survey will be used.

2) The incidence rate refers to the number of new lower back injuries that occur in a sample of a population during a 12 month time period. This value is obtained by dividing the number of new cases occurring in a given time by the number in the sample of the population at risk of injury.

1.4.1 LOWER BACK INJURY IN SPORT

Sport and exercise are stressful by their nature and over-stressful activity may produce injury. Since the 1970s' there has been an increase in the number of people participating in sport and exercise. Consequently, this has led to an increase in the number of sports related injuries (Clement et al., 1981). Williams (1980) stated that there were about 2 million sports injuries per year in the United Kingdom. Of these, 10% required the injured party to take time off work.

Rovere (1987) reported the findings of a survey of injury statistics compiled at a University sports injuries clinic over a five year period. It was found that 5% of all injuries were to the lower back. This cannot be assumed to be the incidence of injury as the population from which the case reports came was not given. Whilst recognising that direct blows and hyperlordotic positions caused lower back injury in some sports, Rovere (1987) stated that overuse and subsequent damage to the lower back was the most common cause. Epidemiological data to substantiate this claim were not presented.

The cumulative effect of spinal loading from exercise, over a prolonged period of time, may have a deleterious effect on the spine and lead to lower back injury. This would fit in with the cumulative trauma model proposed as the possible cause of many of the back problems associated with industrial work (Pheasant, 1991).

The adoption of an ergonomics approach to the study of low-back pain in distance running and CWT includes establishing aetiological factors (personal or environmental) which predisposes the participant to low-back pain. Only then can alterations to exercise programmes and education of participants to reduce the potential of injury, take place. This objective may be achievable using epidemiological surveys, in order to determine the prevalence of low-back pain and establish possible aetiological factors affecting the participants.

1.4.1.1 LOW-BACK PAIN IN DISTANCE RUNNING

Distance running is a repetitive exercise and places repeated stresses on the lower back and lower limbs. The feet of the runner impact with the ground 800-2000 times per mile (or 500-1200 times per km), 50-70 times per minute, with a load equal to 1.6-2.3 times the body weight at heel strike and 2.5-2.8 times body weight at toe-off (Cavanagh and Lafortune, 1980; Munro et al., 1987; Valiant, 1990). Ground reaction forces, which reflect the acceleration of the head, trunk and limbs in direct proportion to their mass, are transmitted through the foot, leg and hip to the lower-back (Miller, 1990). Spinal structures are compressed due to their role in supporting the accelerating mass of the head, arms and trunk. Injuries resulting from running are rarely debilitating but do occur frequently to a large number of people and therefore warrant attention.

Maughan and Miller (1983) reported an increase in the number of running related injuries coincident with the increase in participation. There have been many studies on the relationship between running and injury, but only a few have adopted an epidemiological perspective. Data collected on sports injuries are often taken from clinical case-series reports which are numerator based (Devereaux and Lachmann, 1980; Guten, 1980; Pagliano and Jackson, 1980; Cannon and James, 1984). The advantages of the case-series report are that they are simple to implement, provide information on the relative frequency of injuries and can estimate the total morbidity burden on a health facility (Walters et al., 1985). Information is provided on the relative frequency of injuries, injury history and mode of treatment.

Case-series reports underestimate the level of injury in a population because mild or moderate injuries not presented in the clinic are excluded from the equation. Walters (1985) compared this to the "iceberg phenomenon", in which the greater part of the problem remains undetected. Comparison of findings between case-studies is likely to be compounded by biasing factors in population selection, preventing comparability between studies. The sample is therefore unrepresentative of the whole population.

Case-series reports provide information of use to the clinician in the management of the patient, but do not aid the sports scientist, coach, clinician or athlete in the prevention, cure or reduction injury. Case-series studies cannot provide incidence rates of injury, identify those at risk from injury, or establish risk factors for injuries. The attribution of cause can only be made after experimental study, or inferred from epidemiological studies (Powell et al., 1986; Hoeberigs, 1992).

Brody (1980) analysed case-series data on 3,000 runners examined at university sports injury clinics and found that at some time 60% of them had an injury which prevented them from running. Blair et al. (1987) sent a questionnaire concerning running related injuries, to members of a fitness club who had run 10 or more miles (16 km) per week, in one or more weeks over a three month period. Of the 720 people contacted, 438 (61%) responded and the data collected were retrospective. Injury had stopped 24% of the respondents from training for at least one week over the 3 month period. Devereaux and Lachmann (1983) reported the distribution of injuries among a cross-section of athletes attending a sports injuries clinic. They found that 19.8% of all injuries were reported by middle-distance and long-distance runners and 10.1% of injuries to all athletes were to the lumbar spine. Lower back injury accounted for 8% of all injuries to short-distance runners and 6% of injuries to long-distance runners. Long distance runners included those in marathon, cross-country and orienteering events. Short distance runners included most other track athletes, not just sprinters. This study adopted a case-series approach so that the incidence of lower back injury cannot be ascertained from the data.

Most studies are in general agreement on the anatomical distribution of injuries (Sheehan, 1977; Brody, 1980; Lutter, 1980; Maughan and Miller, 1983; Temple, 1983, Blair et al., 1987). The majority of injuries are to the knee joint (about 28%), the ankle (21%) and foot (18%) (Table 2). Although injuries to the back constitute around 6% of the distribution in these studies, some studies (Sheehan, 1977; Brody, 1980; Temple et al., 1983) failed to report the occurrence of lower back injury, so that this figure is likely to be an underestimation.

The definition as to what constitutes an injury varies in different studies. Koplan et al. (1982) used a non-medical definition of an injury relying on the runner to report injury without guidelines. Lysholm and Wiklander (1987) defined injury as that which reduces training for at least one week and Blair et al. (1987) as that which caused the athlete to stop training for at least seven days. The increase in the severity of injury in these three studies, prior to being called such, illustrates how the definition of injury will affect the cited incidence of injury.

Guten (1981) drew attention to the possibility of misdiagnosis of low-back pain in runners, due to referral of pain from the back to the knee. This would lead to an underestimation of the incidence of back injury and an over-estimation of the incidence of knee injury. This also highlights the difficulty of accurately recording epidemiological data.

Table 2. Anatomical distribution of running injuries

				Maughan +		Blair
	Sheehan	Brody	Lutter	Miller	Temple	et al.
`	(1977)	(1980)	(1980)	(1983)	(1983)	(1987)
Back	----	----	9.0%	3.0%	----	5%
Hip } Groin } Pelvis}	10.1%	----	12.0%	5.0%	3.5%	2%
Thighs	7.5%	----	----	5.0%	----	}
						}10%
Hamstrings	----	----	----	4.0%	5.4%	}
Knee	23.2%	30.0%	29.0%	32.0%	24.8%	31%
Calf	7.0%	15.0%	----	6.0%	3.4%	11%
Shin	14.6%	----	----	6.0%	10.3%	11%
Ankle	19.1%	20% }	----	23.0%	26.3%	15%
		}	50.0%			
Foot	19.5%	---- }	----	13.0%	26.3%	15%

In epidemiology it was important to define which events are to be studied. In doing so it was not essential that every researcher used the same definition, but the definition should include details of the subject, the injury, intrinsic (genetic) and extrinsic (environmental) characteristics and, most importantly, the population from which the sample is drawn (Powell et al., 1986; Hoeberigs, 1992). The incidence of injury, the prevalence of a condition, or the distribution of injury may be influenced by a number of factors:- the choice of sample; subjects dropping out of the survey; non-respondents to survey questionnaires; lack of selection of the subject group; length of the observation period; the definition of injury. In a review of factors related to running injuries, Hoeberigs (1992) compared survey techniques in 10 selected running surveys. It was shown that the choice of subject group may affect the incidence of injury. The incidence of injury was found to be higher among volunteers in supervised training programmes (Pollock, 1977) when compared to those contacted by mailing list, which are higher than in road race entrants (Koplan et al., 1982). In a supervised training programme it is possible to gain injury data on the whole sample. Mailing list surveys rely on the availability of runners through organisations such as race event organisers, and may not include injured and non-injured runners in a population. Race entrants may not include all the injured or unfit runners in a population. These factors will distort the incidence of injury. Caution must be exercised when comparing injury rates between different studies.

Many intrinsic and extrinsic factors (Table 3) which may contribute to musculoskeletal injuries in runners have yet to be investigated epidemiologically. The "characteristics of runners" are those over which the physiological, anatomical and psychological factors, so-called intrinsic variables. These are largely genetically determined and therefore outside the runners' control. However, the runner is able to control many other factors including the "characteristics of running" and the "characteristics of the running environment" which may predispose to injury. These are referred to as extrinsic variables.

Table 3. Possible causes of musculoskeletal injury in runners

Characteristics of runners	Characteristics of running	Characteristics of the running environment
Age	Distance	Terrain
Sex	Speed	Surface
Structural abnormalities	Stability of pattern	Climate
		Time of day
Body build	Form	Shoes
Experience	Stretching	
Susceptibility	Weight-training	
Past injury	Warm-up/cool-down	

(Adapted from Powell et al., 1986)

Maughan and Miller (1983) noted that prior to the popularization of distance running, the endurance races were restricted to a limited number of athletes who were well adapted to the stresses that such training and racing impose on the body. Although it is possible to complete a marathon course without training, safe, successful and relatively comfortable completion requires a substantial degree of training. Small, graded increases in stress produce physiological adaptations (Powell et al., 1986). Longer and more intense exposure may exceed the body's capacity to adapt and could result in injury. A large and relatively abrupt increase in the stress on the musculoskeletal system is more likely to lead to injury than a small incremental change. The training programme adopted is under the runner's control and needs to be stressful enough to provide a training stimulus. Excessively stressful or inappropriate training could lead to "over-training" and cause damage or injury.

Pollock et al. (1977) used a prospective cohort design, involving 70 men aged 20 to 35 years, in a 20 week jogging programme. Subjects were assigned to groups training three times per week for either 15, 30 or 45 min per session, or to groups training 1, 3 or 5 times per week. The exercise regimen consisted of jogging at 85-90% of maximal heart rate. The incidence of injury was found to be 22%, 24%, and 54% for the group training 15, 30 and 45 min, and 0%, 12% and 39% for the group training for 1, 3 and 5 times a week. It was concluded that greater frequency and duration of training are related to an increased risk of injury. The higher injury rates with a high training volume (mileage) adds credence to the argument that incidence of injury increases with an increase in training mileage.

The mileage run per week is the training variable most frequently related to increased risk of injury (Pollock et al., 1977; Koplan et al., 1982; Reilly and Foreman, 1984; Blair et al., 1987; Powell et al., 1986; Brunet et al., 1990; Hoeberigs 1992). Reilly and Foreman (1984) found two peaks of injury incidence, at training volume thresholds of over 40 miles (64 km) per week and over 80 miles (128 km) per week. The amount of training or mileage does not account for all running injuries. It is therefore important to use epidemiological techniques to investigate alternative extrinsic and intrinsic factors (Table 3), which may influence injury risk. Runners are more also liable to injure a previously injured site (Powell et al., 1987; Hoeberigs , 1992). This could be because the initial cause of injury may remain or the injury may not have healed to its pre-injured state.

Koplan et al. (1982) using a randomised trial design, contacted 2,500 race entrants by postal questionnaire, in order to collect details on their training habits and injuries. The questionnaire was returned by 57% of recipients. The incidence of injury was found to be 35%, with a higher rate being associated with a higher weekly mileage. Koplan et al. (1982) contacted non-respondents to eliminate the possibility of skew due to their omission. No significant difference was found in a random sample of 138 non-respondents contacted by telephone. This finding indicated that extrapolation to the whole population from the sample did not introduce bias. However, injuries to runners who did not enter the race could not be taken into account, which would reduce the incidence rate.

The average weekly mileage undertaken by a typical recreational marathon runner is 34 (17) miles or 55 (27) km (Maughan and Miller, 1983). Elite performers may regularly exceed 100 miles (160 km) per week. It has been found that 58-77% of injuries to marathon runners occur during training (James et al., 1978; Reilly and Foreman, 1984; Maughan and Miller, 1983), and that one or more training faults (such as excessive training mileage, rapid change in routine, change in running surface) are attributed to causing 72% of injuries (Lysholm and Wiklander, 1987).

Brunet et al. (1990) investigated the pathogenesis of running injuries in 1505 competitive and recreational runners (1130 male and 375 female). They used a retrospective cohort design, a 33-item questionnaire, in which the runners were asked questions relating to their training regimens, footwear, anatomical abnormalities and injuries. No details were given of the population from which the sample was taken.

The runners were asked whether they experienced low-back pain. The results showed a prevalence rate of 35% for male and 34% for female runners. When asked, 15% of male and 11% of female runners reported being diagnosed as having vertebral or disc problems. It was not indicated whether these back complaints were related to running. Injury was unrelated to body weight, height, foot type, foot strike (forefoot or heel), frequency of running or number of years running. Neither was there a difference in injury rate between those running primarily on asphalt compared with concrete. Age was found to be positively related to an increase in the reported number of hip, foot and vertebral or disc complaints. This trend was also typical in the non-running population. Injuries were also unrelated to whether the runner never stretched (i.e employed flexibility exercises), stretched before running or stretched before and after running. It should be noted that details of the muscles and tendons stretched were not given. Inferences cannot be made about the relationship between stretching, flexibility and joint range of motion, without measuring flexibility.

A high weekly mileage was significantly related to an increased prevalence of stress fractures, foot injury, achilles injury and hip injury, but not to back injury in men. Brunet et al. (1990) found that the prevalence of low-back pain, vertebral or disc problems increased with an increase in weekly mileage only in women. They also found that 15% of men and 16% of female runners reported a leg length inequality and this was significantly related to an increase in the number of reported stress fractures (diagnosed by a doctor), hip pain, low-back pain, vertebral and disc problems (diagnosed by a doctor). Assessment of leg length inequality was not made from anthropometric measures, but from responses to the question: "Do you have a diagnosed leg length discrepancy? a) No; b) Yes, 0-1 inch; c) greater than one inch. Intra-observer error and reliance on self-reporting of discrepancies by the runners will have introduced errors into this response.

Lack of running experience may be a possible risk factor predisposing to injury. Novice runners have poor technique and little adaptation to the physiological and mechanical stresses imposed by running. However, Koplan et al. (1982) and Blair et al. (1987) found no relationship between risk of injury and the number of years of running experience.

The "Characteristics of running" (Table 3) also include training activities supplementary to running such as weight-training, stretching, and warm-up and warm-down which may reduce the risk of injury. These adjuncts to training could reduce injury by increasing joint flexibility and stability, and altering muscle temperature towards and optimal level (Powell et al., 1986).

Koplan et al. (1982) found that age, sex, number of years running experience, training intensity (indicated by mean running speed) and body mass index (weight/height^2) were not independently related to incidence of injury. No current data suggest that age or sex protects from or leads to injury.

The risk of injury may also be affected by "characteristics of the runner" (Table 3) which are largely genetically determined. Individual susceptibility towards injury is referred to as injury proneness. Proneness could apply at a physiological, psychological or biomechanical level. Powell et al. (1986) presumed that such factors were related to susceptibility, but found no evidence of such a relationship in their review of epidemiological studies. They highlighted individual "form" as a possible factor in causing injury. However, "form" needs to be defined accurately before an investigation of this area is possible. Lees (1988) hypothesised that ground reaction forces in running may differ considerably within an individual from test to test. This implies that running "form" or technique may vary from day to day. If this hypothesis were substantiated, then injury risk could in fact vary on a day to day basis.

"Characteristics of the running environment" (Table 3) may affect the probability of injury. The load on the body will vary according to the terrain over which running takes place. The biomechanics of spinal loading will also depend on whether running is performed on the flat, uphill or downhill. However, Blair et al. (1987) found no difference in incidence of injury between runners who trained primarily on hilly and on level terrain. Neither was there an association between synthetic (running track) and road surfaces and injury rate, or between time of day and injury rate. It is possible that good quality footwear protects against injury by providing support, stability and cushioning. Poor quality footwear could contribute to injury risk, but information is largely anecdotal (Blair et al., 1987).

There is a paucity of demonstrable risk factors from running injuries research, which Hoeberigs (1992) attributed to the relatively "young state" of running epidemiology. Epidemiological research should be directed towards obtaining information on extrinsic factors, over which the runner has control, and the effect that these have on the incidence of injury. If an extrinsic factor is shown to increase the risk of injury, the runner's training regimen could be altered to reduce that risk. Such risk factors include frequency of running and distance run, changes in weekly mileage, speed of running, warm-up and cool-down routines, running surface, footwear and time of day. Comparison of injury rates between injured and uninjured runners may provide important information as to the cause of an injury problem and subsequently lead to prevention.

It has been demonstrated that studies of running related injuries do not possess a standard format. The variables under investigation in each study are not always consistent, neither are the designs of studies, populations, the sampling methods and the time scales. As a consequence when designing a study of running injuries there is no single model to follow.

This study will use retrospective and prospective epidemiological survey techniques to determine the prevalence and incidence rates of low-back pain in distance runners. The relationship between extrinsic training variables and low-back pain will be explored, to determine any link. The main extrinsic variables under investigation are:- the number of runs per week; the total weekly mileage; the number of miles per run; the time taken for each run; the speed of running; the distance of each run; the percentage of time spent running at a steady pace; the percentage of time spent running on the road; the number of hours spent running each week; and the number of days spent running each week. Attitudes towards training, warming-up, warming down and injury will also be examined.

1.4.1.2 LOWER BACK INJURY IN CIRCUIT WEIGHT-TRAINING

Circuit weight-training (CWT) is utilised for training the oxygen transport system and for general training of the musculoskeletal system. During CWT spinal loading may cause almost pure axial compression (e.g. when performing an overhead press). Changes in the position of the weight lifted and of the spinal column during lifting will alter the degree of axial compression. External forces may cause upper vertebral bodies to tilt in relation to lower vertebral bodies and will impose moments inducing torsion. For example, during a barbell curl bending moments are caused by loading eccentric to the centre of rotation of the vertebrae. These forces will be associated with counter moments generated by the spinal musculature to maintain posture or provide movement. This could lead to large compressive forces on the spine (Smith and Fernie, 1991).

The acute and chronic physiological responses to circuit weight-training (CWT) have been documented by various authors (Pollock et al., 1969; Pollock, 1973; Gettman et al., 1978; Gettman and Pollock, 1981; Hempel and Wells, 1985). However, there is a paucity of epidemiological data on injuries resulting from CWT. Davies (1980) stated that weight-lifting was responsible for proportionally more back injuries than any other sport. No data were presented to support the claim and the type of weight-training was not defined.

Basford (1985) defined six weight-training techniques: Power lifting; Olympic weight-lifting; Body building; Weight training; Conditioning; and Circuit weight-training. In all of the weight-training activities outlined the structure of the programme differs. This applies in terms of repetitions, speed of lifting, duration of training and equipment used. These techniques were described as follows:

i) Power lifting - a competitive form of lifting in which training is aimed at producing a higher one repetition maximum (1 RM) lift. Three lifts are involved: the bench press, squat and deadlift.

ii) Olympic weight-lifting - a competitive form of lifting in which training is aimed at improving the maximum lift, performed once, the so-called one repetition maximum (1 RM) lift. Two lifts are used: the clean and jerk and the snatch.

iii) Bodybuilding - a form of training in which the object is to "sculpture" the body by inducing muscle hypertrophy. The development of strength is not an object of training but occurs in the process of training.

iv) Weight-training - a supplementary activity used by sports people, whose primary interest is in training for their sport rather than for strength improvements per se.

v) Conditioning - "body conditioners" may not be involved in other sports, use lighter weights than body builders and lifters. They are more inconsistent in their routines, and are less likely to have had formal training than their counterparts in other categories (Basford, 1985).

vi) Circuit weight-training is used with the intention of stimulating an aerobic training effect, though strength changes commonly ensue. The physiological effects of CWT and the methods of training involved are discussed in more detail in Section 6.4.

Case-series reports provide the bulk of the information relating to injury resulting from weight-training. The populations from which the data are drawn, the injuries sustained and the methods of weight-training are often poorly defined.

Billings et al. (1977) studied 100 men and women who attended a sports injuries clinic, having developed low-back pain from a sports injury. They found that weight-training was the single most common cause of lower back injury, accounting for 38% of all training injuries. Back injury restricted performance in 34% of all cases and prevented training in 51% of the athletes, prior to treatment. Almost half of the cases reported (49%) were new episodes of back pain. The remainder were recurrent injuries. Of the 51 athletes with a history of low-back pain, 37 were previous sport-related injuries. The intervertebral disc was implicated in 64% of diagnoses.

Cannon and James (1984) studied 197 patients attending a sports injuries clinic over a four year period. The study arose from observations that increasing numbers of people were attending the clinic suffering from low-back pain, an increase from 2% in 1978 to 8% in 1981. Mechanical low-back pain, prolapsed intervertebral disc and degenerative changes were diagnosed as being responsible for 68% of these injuries. It was found that low-back pain symptoms lasted for an average of 41 weeks. If the group was split into acute and chronic sufferers, the mean durations were 13 weeks and 58 weeks respectively. This illustrates that even though the absolute number of cases presented was small, low-back pain had significant consequences for the sufferer, in terms of the length of the recovery period.

Basford (1985) maintained that mild low-back pain was a complaint that was occasionally present in most weight-lifters, although the term "weight-lifter" was not qualified. The most frequent cause of injury was reported to be incorrect training techniques producing hyperextension of the lumbar spine, though no data were provided to support this argument. Basford (1985) claimed that if poor technique was the cause of injury, this should be rectifiable by modifying training.

Brady et al. (1982) described injuries related to weight-training in 80 high school athletes, who presented themselves for medical treatment over a four year period. The mean age of the athletes was 15.8 (range 13-19) years. In 37 of the athletes, injury could have been caused by an alternative sporting activity. In the remaining 43 athletes, weight-training was the only likely causal factor. Twenty-nine of the athletes had lumbosacral pain. Seven of these required hospital treatment and four needed surgery.

Brady and colleagues (1982) claimed that their review of 80 cases "demonstrated a significant incidence of injury due to weight-training programs". This is an unwarranted conclusion as no data were given on the population denominator from which this sample of athletes was drawn was given. If, for example, the total population of athletes involved in weight-training was 80 and the number reporting injury was 80, the incidence rate over the four year period would have been 100%. If the number of athletes involved in training was 8000 and the number reporting injury was 80, the incidence rate would have been 1% over the same period of time. The total population to which the weight-trainers belonged, which would include injured and uninjured trainers was not presented. Therefore, it is not possible to predict the incidence of injury among the athlete population from the data on injured athletes without reference to those uninjured.

In documenting the case-histories of the athletes, Brady et al. (1982) observed that the vast majority of injuries were insidious, with the athlete unable to indicate a precise time of onset. This obviously leads to difficulty in assigning mechanisms which cause injury. It also highlights the usefulness of epidemiological techniques which allow the analysis of possible associations between aetiological factors and injury.

The authors associated a particular design of weight-training apparatus, designed to increase vertical jump height, with an abnormally high proportion of lower back injuries. Adopting a squatting posture, the athletes place their shoulders in a harness attached to a load and thrust upward. The assumption that this apparatus excessively loaded the spine may be valid but can not be substantiated by the case-series method of data collection alone. A survey of 402 institutions showed that 71% of the 349 which responded used this type of apparatus. No comparative data were given on the availability and usage of other weight-training systems. Nor were data on the relative and absolute amount of time injured and uninjured athletes used the system presented. The denominator variable was again absent from the calculation. Therefore it was not possible to attribute relative and absolute risk of lower back injury to use of this type of apparatus.

Brady et al. (1992) concluded that it was not "epidemiologically necessary to wait for an epidemic before reporting the trend of weight-training injuries". It is epidemiologically necessary to include the population denominator in the reporting of incidence of injuries attributable to weight-training. Without this essential information trends and epidemics cannot be identified.

Marcinik et al. (1987) compared the sprain and strain injury rates during aerobic/calisthenic (ACAL; n=722) and aerobic/circuit weight-training (ACWT; n=447) programmes. The subjects were Naval recruits undergoing 8 weeks basic training, and were randomly assigned to each group. The ACAL group performed sit-ups, push-ups, flutter-kicks, "8-count body builders", and jumping jacks (no details of the actual techniques were given). The ACWT routine comprised the bench press, shoulder press, hip-flexor, knee extension, pull-up, arm curl, latissimus pull-down, leg-press, arm dip and inclined sit-ups, performed on multi-station apparatus. Two circuits were performed at 60% 1 RM, with work:exercise periods of 15 s : 15 s. The aerobic exercise consisted of running and was identical for both groups.

There were 138 injuries in the 8 week period. The ACAL routine caused 98 of these injuries and the ACWT routine 40. Lower back injury accounted for 12% of the total injuries, the ankle and foot 56.5%, the knee and leg 27.5% and the shoulder and arm 7.2%. A chi-squared analysis showed that this difference was attributable to more foot and ankle injuries in the ACAL group (63/98) compared with 15/40 in the ACWT group. The ACAL routine caused 7 lower back injuries out of a total of 98 injuries, whereas the ACWT routine caused 5 lower back injuries in a total of 40, this difference being non-significant. It is not possible to determine whether the injuries to the lower back were attributable to CWT, running or an interaction effect.

Apart from the study by Marcinik et al. (1987), the data in the studies described in this section were derived from case-series reports. Case-series reports rely solely on self-reported occurrences of injury and do not take into account the population from which the sample was drawn (Section 1.4.1.1). Hence it is not possible to ascertain the incidence and prevalence of an injury in a population from this sort of data. The above studies do not fully define the types of weight-lifting or weight-training which caused injury.

There are a number of different weight-training methods (Basford, 1985) which would alter the mechanisms causing injury according to the type of training routine. The incidence, risk and anatomical distribution of injury may also alter. In CWT the external load lifted is relatively light, typically 40% of the trainer's maximal effort for a lift (Gettman and Pollock, 1981). Typically, 3 circuits of 10 exercises, with 15 repetitions of each exercise are performed. This would mean that about 450 lifts are incorporated into a CWT regimen, applying a variety of forces (compressive, tensile, shearing and torsional) which load the spine during a training session. Sound epidemiological information on injuries ascribed to CWT are not available. It is therefore necessary to attempt to acquire these data through an epidemiological survey of injuries among participants.

2 FUNCTIONAL ANATOMY OF THE SPINE

2.1 THE STRUCTURE AND FUNCTION OF THE SPINAL COLUMN: AN OVERVIEW

The main functions of the vertebral column are to support the head and trunk and to protect the spinal cord. The vertebral column's structure has developed in order to perform this duality of function. It must meet the two contradictory mechanical requirements of rigidity and plasticity. This is achieved by the multiple components of the system:- 7 cervical vertebrae; 12 thoracic vertebrae; 5 lumbar vertebrae; and the intervertebral discs (Figure 1). These are interlinked by muscles and ligaments which control and restrict movement.

In the sagittal plane, the vertebral column shows four curves:

1) the sacral curve is fixed due to fusion of the sacral vertebrae, and extends from the coccyx to the lumbosacral junction;
2) the lumbar curve is concave posteriorly when standing and extends from the lumbosacral junction to T12 (Figure 2).
3) the thoracic curve is convex posteriorly and extends from T12 to T2;
4) the cervical region is concave posteriorly and extends from T1 to the occiput (Figure 1).

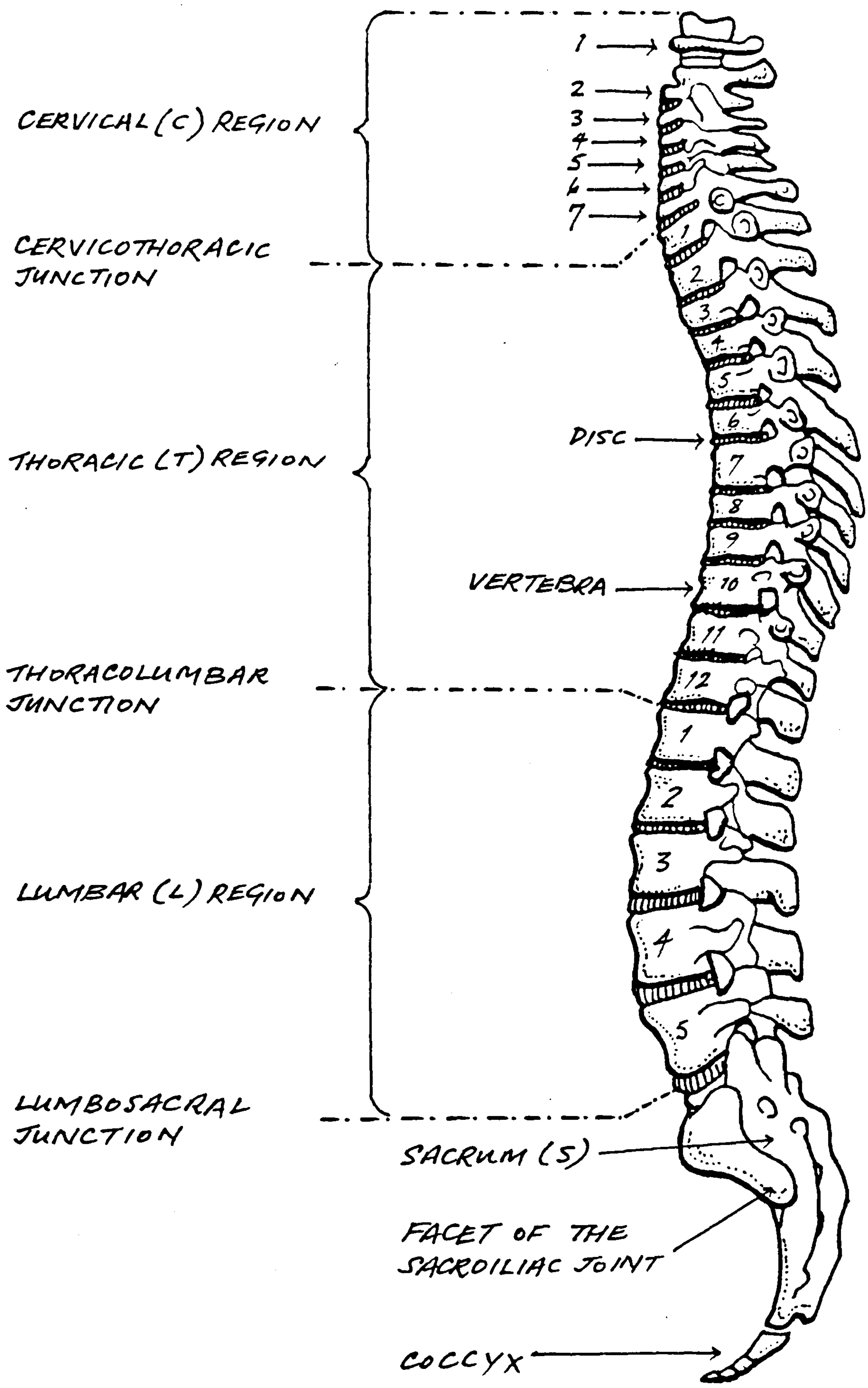


Figure 1. A lateral view of the vertebral column viewed from the left

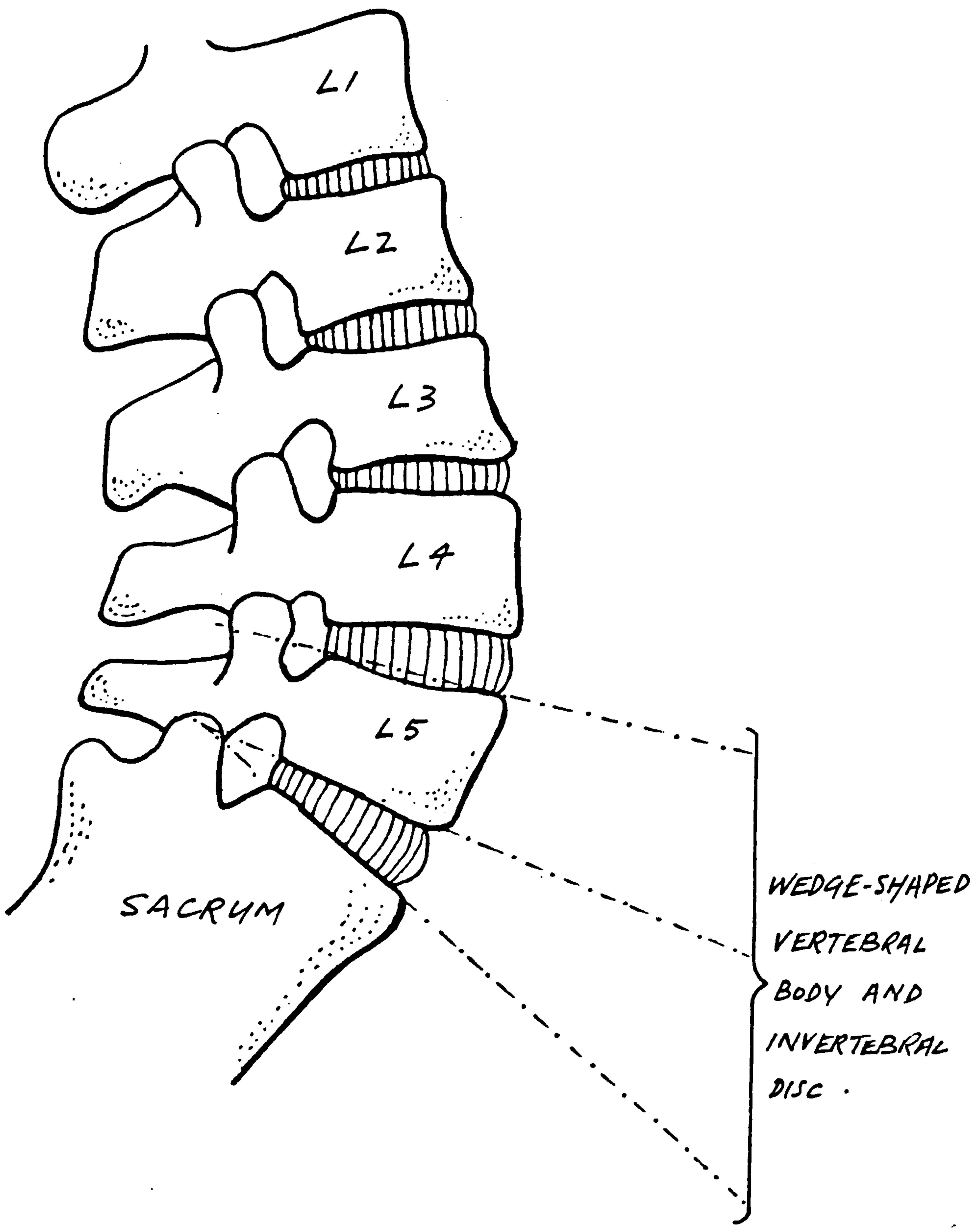


Figure 2. Lateral view of the lumbar spine viewed from the right

The alternating of bony and soft tissue structures in the vertebral column allows a functional distinction to be made between passive and active segments of the vertebral column (Kapandji, 1974). The passive segment consists of the vertebrae. The active segment consists of the intervertebral discs, the intervertebral foramen, the articular processes including the capsular ligaments, the ligamentum flavum and the supraspinous and interspinous ligaments. The mobility of the active and passive segments enables the vertebral column to move. Individual movements between vertebrae are relatively small, but sizeable movements are achieved as the net effect of multiple vertebral joint motion. This system allows for the absorption of compressive forces, firstly through direct and passive absorption at the intervertebral disc and secondly, through indirect and active absorption via the ligaments and paravertebral muscles.

The muscles surrounding the vertebral column contract to produce motion and resist the pull of gravity (Alexander, 1985), they also provide passive resistance to motion. Floyd and Silver (1955) demonstrated that the erector spinae muscles were electrically silent when stretched in full flexion. When standing in a relaxed posture, there is little activity in the paraspinal musculature. On leaning in the sagittal or frontal plane, there is an instantaneous contraction of the muscles opposite to the direction of inclination, so as to maintain posture.

2.1.1 THE VERTEBRAE

A typical vertebra consists of an anterior portion forming the vertebral body and a posterior portion forming vertebral arch. The vertebral body is a 'kidney shaped' cylinder, broader than it is high. It comprises of an external layer of cortical bone filled with cancellous bone. The cancellous bone consists of three main systems of trabeculae (vertical, oblique and horizontal) which act as supports strengthening the structure (Oliver and Middleditch, 1991).

The 'horseshoe shaped' vertebral arch attaches to the vertebral body enclosing the vertebral foramen which is triangular in cross-section. It is formed by the lamina laterally, the pedicles posteriorly and the articular processes. A spinous process is attached posteriorly to the midline of the arch. Two further processes, the transverse processes, protrude laterally from the arch near the articular processes (Figure 3). These constituents lie in anatomical correspondence along the length of the vertebral columns, forming three pillar like structures. The major pillar consists of the vertebral bodies joined by the intervertebral discs. The two smaller posterior pillars are formed by the articulating facet joints and form arthrodial joints.

The space between these structures forms the spinal canal which carries and protects the neural tissue (Kapandji, 1974).

2.1.2. THE LIGAMENTS

The fibrous ligaments and intervertebral discs link adjacent vertebrae. There are 6 sets of ligaments:

i) The anterior longitudinal ligament stretches from the basi-occiput to the sacrum along the anterior surface of the vertebral column;

ii) The posterior longitudinal ligament extends from the basi-occiput to the sacrum on the posterior aspect of the vertebral body. The anterior and posterior ligaments are attached to the discs at each intervertebral level.

The vertebral arches are inter-connected by several ligaments:

iii) the ligamentum flavum is a strong ligament joining successive laminae and "closes" the vertebral canal;

iv) the interspinous ligament is continuous posteriorly with the supraspinous ligament, which is attached to the tips of the spinous processes;

v) the intertransverse ligament, as its name implies, adjoins adjacent transverse processes;

vi) a capsular ligament adjoins adjacent articular processes. Ligaments provide strong mechanical resistance to excessive spinal motion (Adams et al., 1980).

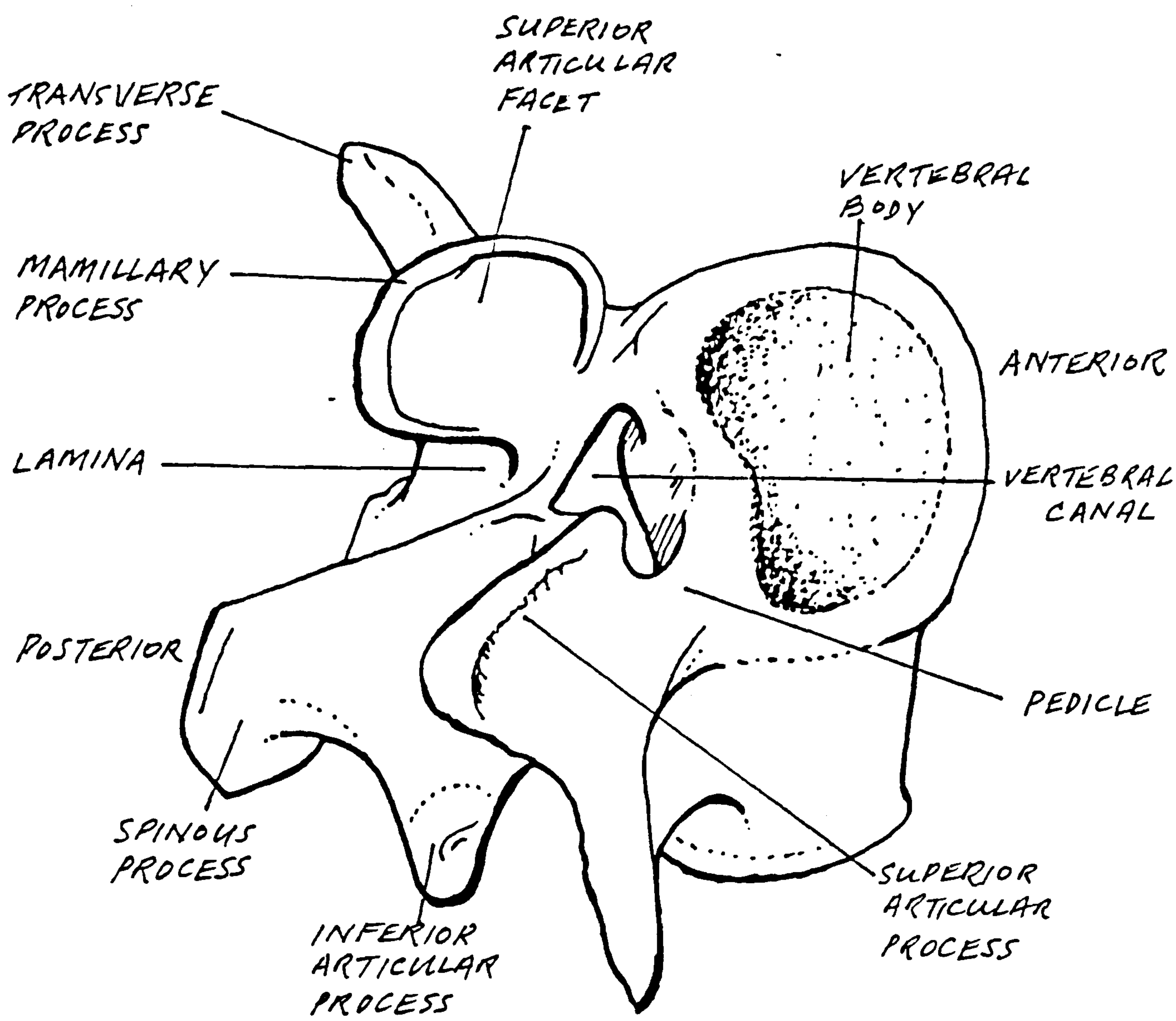


Figure 3. A typical vertebra viewed superiorly from the right.

2.1.3 THE INTERVERTEBRAL DISC: CREEP AND HYSTERESIS

The intervertebral discs act both to permit and restrict movement of the intervertebral joints and to transmit loads from one vertebral body to the next (Oliver and Middleditch, 1991). They lie between successive vertebrae and can be anatomically divided into two parts: the annulus fibrosus, a collagen fibre matrix; and the nucleus pulposus, a hydrophillic proteoglycans gel (Figure 4). The most central of the annular fibres are in close contact with the nucleus pulposus to which they tightly bind.

Much of the knowledge of the function of the vertebrae, intervertebral discs and associated structures comes from experiments in which load have been applied to motion segments in vitro. Motion segments are the intervertebral disc and the associated superior and inferior vertebral bodies.

The water content of the intervertebral disc has been shown to be subject to diurnal variation (Adams and Hutton, 1987; Adams et al., 1990) and represents an equilibrium between opposing mechanical and osmotic forces. A mechanical load on the spine will dehydrate the intervertebral disc if the forces exceed the swelling pressure (osmotic forces) of the hydrophillic proteoglycans in the intervertebral disc (Adams and

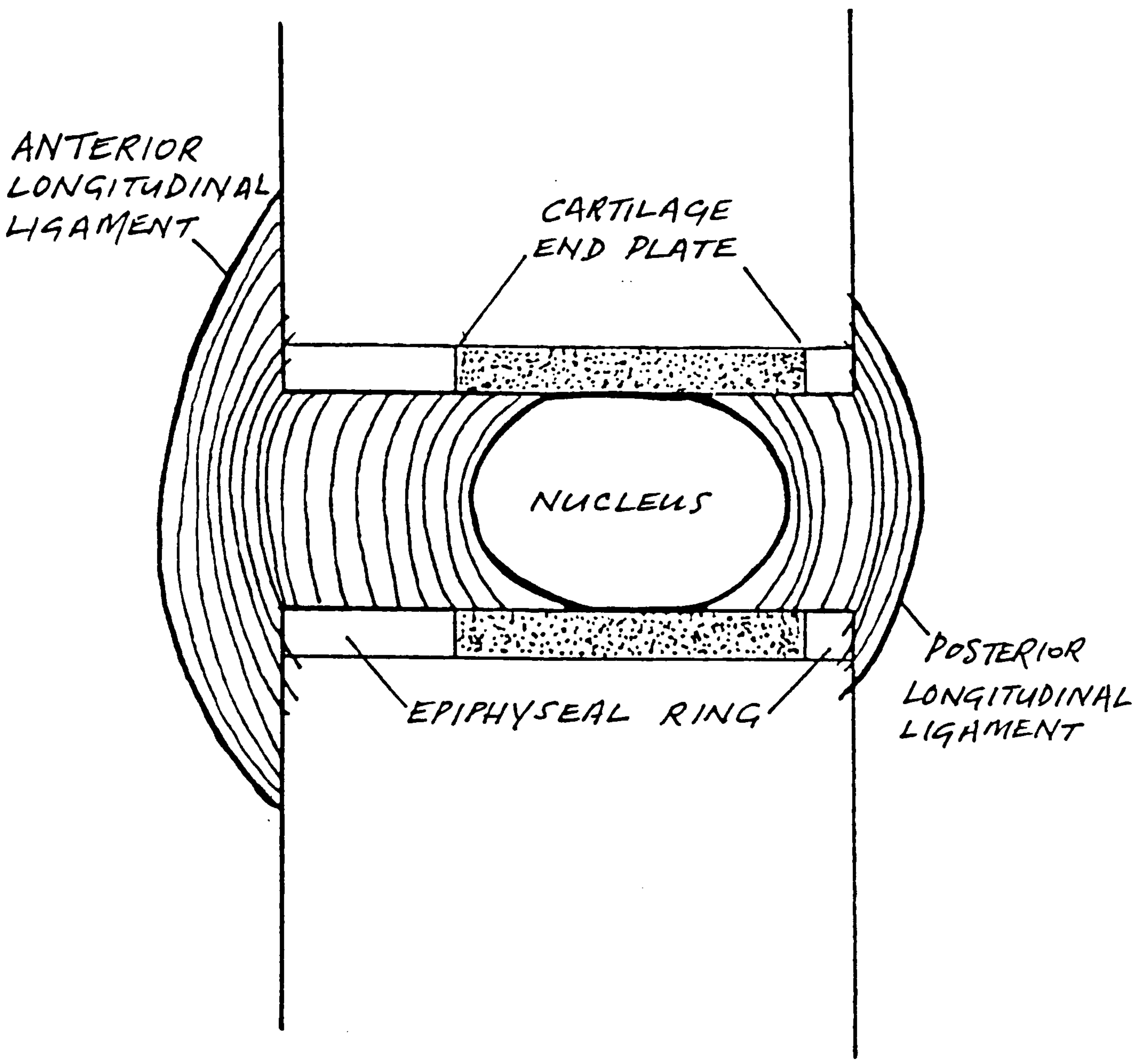


Figure 4. A schematic representation of a motion segment showing the structure of the intervertebral disc.

Hutton, 1983). Virgin (1951) observed moisture on the surface of motion segments under heavy axial loading. The changes in hydration of discs subjected to axial loading are reflected in changes in motion segment height (Figure 5) which are also partially attributable to extension and contraction of annular fibres (Koeller et al., 1984) and vertebral end-plate compression (Brinckmann et al., 1981). This occurs along the length of the spinal column and will alter the mechanical functioning the spine (Kazarian, 1972; Kazarian 1975; Adams and Hutton, 1980; Twomey and Taylor, 1980; Brinckmann 1988).

This phenomenon is known as creep, which refers to the progressive deformation of a structure under constant load when stressed below fracture point (Twomey and Taylor, 1982). Creep is characterised by an immediate elastic deformation of the motion segment and a subsequent slower creep phase (Kazarian, 1975). It results from progressive polymer distortion and fluid loss which reduces the disc height and leads to stiffening of the disc. Stiffness refers to the resistance to deformation of a structure (Twomey and Taylor, 1982).

When the spine is unloaded following creep it will return to its previous state providing its elastic limit has not been exceeded, a process known as hysteresis (Twomey and

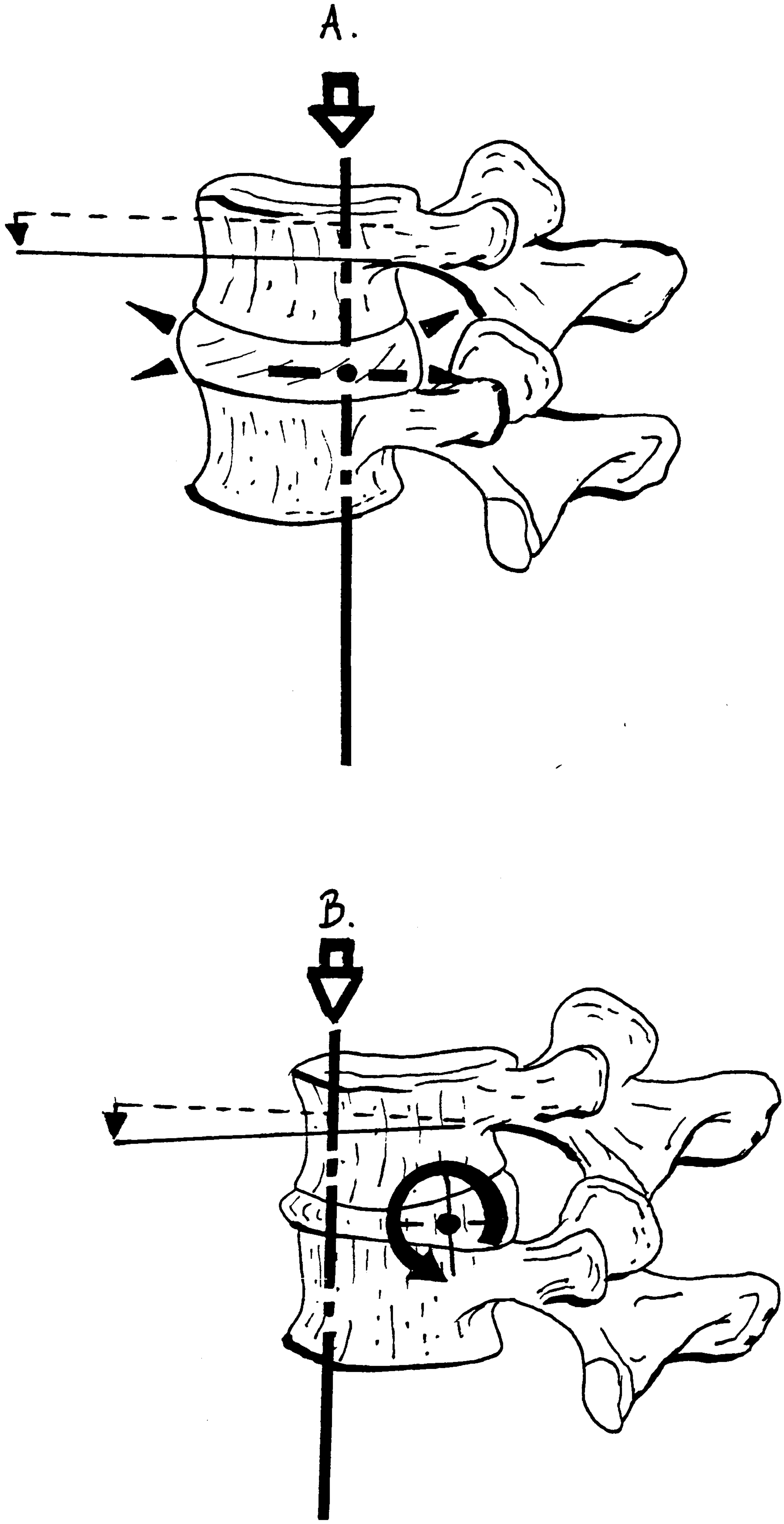


Figure 5. A motion segment under A) axial compression over the centre of equilibrium and B) off centred loading inducing torque and tension in the posterior annular fibres. (After Smith and Fernie, 1991)

Taylor, 1982). Hysteresis in the spinal column varies with the age of the spine and has been shown to be prolonged and less complete in older specimens (Virgin, 1951; Twomey and Taylor, 1982). The nucleus pulposus loses its ability to imbibe water with age and becomes stiffer due to changes as in the structure of the proteoglycans. Hence it has a diminished capacity to withstand compressive forces (Twomey and Taylor, 1991). Twomey and Taylor (1982) also demonstrated that motion segments from older spinal columns showed greater flexion creep deformation than the younger motion segments.

Adams and Hutton (1983) creep-loaded motion segments for 4 hours with a force equal to body weight. They calculated that the overall fluid loss from the disc was about 11%. As the total water content of the disc is about 80% this would reduce the total volume or height of the disc by about 9%, equivalent to 0.9-1.1 mm. Therefore, in an average disc about two-thirds of disc height loss is due to expulsion of water. The remaining third is due to creep deformation of the vertebral body and the annulus fibrosus.

Twomey and Taylor (1982) examined the effect of flexion creep deformation on cadaveric motion segments. They found that flexion creep was dependent on the magnitude of the load applied and progressed with time. Most creep occurred in the initial stages of loading. In older segments creep increased and continued over a longer time period. Hysteresis showed a common recovery curve in motion segments from young cadavers regardless of the load applied. In older specimens recovery was slower and varied in relation to the load applied.

Adams and Hutton (1980) showed that in simulated lumbar extension the apophyseal joints resisted 16% of the intervertebral compressive forces, after disc height had been reduced by a period of sustained loading. In slight flexion the apophyseal joints had no role in load distribution. This demonstrated that the lumbar intervertebral disc plays the major role in resisting intervertebral compressive forces regardless of posture. During flexion the centre of rotation of an intervertebral joint is within the intervertebral disc (Smith and Fernie, 1991). This results in tension in the posterior spinal ligaments and posterior annular fibres. Adams et al. (1980) examined the role of spinal ligaments and intervertebral disc in resisting flexion under physiological load conditions. The initial analysis was performed on the intact motion segment. Subsequently the supraspinous ligament, interspinous ligament, ligamentum flavum and capsular ligaments were cut, and the experiment repeated. The results showed that at low angles of flexion the supraspinous and interspinous ligaments did not resist flexion. At half-full flexion and full flexion they provided 8% and 19% of the resistance. The ligamentum flavum resisted 28% of the load at half flexion and 13% at full flexion. The capsular ligaments resisted 25% at half flexion and 39% at full flexion. The intervertebral disc resisted most of the flexion moment, 29% at full flexion and 38% at half flexion. This indicates that the intervertebral disc plays the major role in resisting compressive forces in flexion as well as in extension.

Adams et al. (1987) performed two complementary experiments, in vivo and on cadaver motion segments. They examined diurnal variation in the degree of flexion of the lumbar spine. They found that in vivo lumbar flexion increased by about 5^{o} throughout the day. In motion segments subjected to flexion creep simulating axial loading, the increase in flexion was $2\text{-}3^{o}$, equivalent to 12^{o} in the whole spine. The reason for the discrepancy was probably the protective role of the thoracolumbar fascia limiting flexion in vivo. Due to the loss in intervertebral disc height in the afternoon the collagen and elastin of the annular fibres and ligaments slacken to allow the increased range of motion.

More recently attempts have been made to measure creep in vivo (McGill and Brown, 1992; Kaigle et al., 1992). McGill and Brown (1992) followed the time course of flexion creep in 27 male and 20 female subjects sitting in full lumbar flexion for 20 min. Flexion increased by

5.5%, a value similar to that found in cadaver motion segments (Adams and Hutton, 1987). Recovery took longer than flexion creep showing viscoelastic hysteresis properties. Most of the original stiffness was recovered soon after relaxation. The results showed that creep loading reduced the resistance of the spine to bending and that the bending stress on the disc was greatest in the morning. The practical applications of this work are that temporary joint laxity can occur when full flexion is maintained. Postures to intersperse flexion with extension should be assumed intermittently to reduce this problem, as temporary joint laxity could result in hyperflexion injury.

A more invasive technique was used by Kaigle et al. (1992) on two subjects. Strain gauges were fixed to the L4 and L5 spinous processes by means of two 10 mm intraosseous pins. The subjects sat in an upright posture for 5 min and showed segment height losses of 0.2 mm and 1.1 mm. The second subject showed a change of 0.9 mm on a second trial. There is not enough data from this study to make valuable comparisons with other studies. Due to the invasive nature of the technique, it is unlikely that this technique will be widely used.

Research findings indicate that responses to loading in motion segments can simulate responses in vivo. Adams et al. (1987) assumed loss in disc height would be proportional to the disc height of the spinal region. The disc height ratio for the lumbar, thoracic and cervical regions is 9:5:3. They calculated that loss in lumbar disc height, multiplied by the ratio for each region, multiplied by the number of discs in each region, would give the total change in spinal length for a given load. They showed that a physiological load of 1000 N, simulating light manual labour, applied for 6 hours produced an average loss of 1.53 mm in lumbar intervertebral disc height.

Using the lumbar compression data they calculated the total change in spinal height as follows:

Lumbar	5	x (1.53 x 9/9) =	7.65 mm	(36.6%)
Thoracic	12	x (1.53 x 5/9) =	10.20 mm	(48.8%)
Cervical	6	x (1.53 x 3/9) =	3.06 mm	(14.6%)
Total spinal length change			20.91 mm	

These findings are similar to the 19.3 mm diurnal change in stature observed by Reilly et al. (1984). Spinal length accounts for 40% of total body height, with approximately 33% of total body length made up of intervertebral discs. Any change in disc height will affect spinal length and ultimately stature.

Data from cadaver studies show how intervertebral dimensions are altered by compressive loading.

Compressive forces increase when the body is subjected to external loading as in circuit weight-training or impact loading, as in running, due to the increased mechanical load and the compression induced by muscular action (Smith and Fernie, 1992). It has been demonstrated that the load on the spine in physical activity can be measured using changes in stature (Eklund and Corlett, 1984; Boocock et al., 1986). The implications of this development as an ergonomics tool for estimating spinal loading and its implications for back pain research are discussed in Section 3.3.

3. METHODS OF MEASURING RESPONSES TO LOADING

Physical exercise places a variety of demands on the body; physiological, psychological and physical. The body's response to each of these demands depends upon the intensity and the duration of the exercise, the mode of exercise and the physical fitness of the participant. Physiological, psychological and physical changes brought about by physical exercise are amenable to measurement by a variety of techniques. The adoption of an ergonomic approach to the problem of spinal loading and low-back pain during aerobic exercise, requires the use of several methodologies to provide a more comprehensive understanding of the physiological context in which spinal loading is incurred.

3.1 PHYSIOLOGICAL INDICES OF LOADING

The physiological demands of a task inducing high aerobic loading can be assessed by monitoring oxygen consumption and heart rate. Heart rate shows a linear relationship with work intensity after about 120 beats per min (or when stroke volume is maximal) and oxygen consumption shows a linear relationship to work intensity upto a maximal value where it plateaus (Astrand and Rodahl, 1986). It has been shown that an individual's maximal aerobic power is an important factor in determining the capacity for aerobic exercise. Indeed endurance athletes have a greater VO_2 max than untrained individuals, elite marathon runners greater than non-elite runners and, within limits, VO_2 max is inversely related to performance time (Astrand and Rodahl, 1986). It should be noted that distance runners do not operate at maximal oxygen uptake when racing. The ability to complete a marathon quickly has been shown to be related more closely to the fraction of maximal oxygen uptake which can be used, the fastest runners working at a higher proportion of their VO_2 max (Maughan and Leiper, 1983; Sjodin and Svedenhag, 1985).

The oxygen uptake during submaximal exercise depends on the supply of oxygen to the exercising muscle via the circulation. The cardiac output increases linearly with increases in exercise intensity and is itself a function of heart rate (HR) and stroke volume (SV). Heart rate responds differently to static and dynamic muscular action. The intensity of a static, or isometric, muscle action is usually expressed as a percentage of maximal voluntary contraction (MVC). Endurance time is inversely related to muscle tension when expressed as a percentage of MVC. Isometric muscle actions can limit blood flow to exercising muscles, producing anaerobic conditions and increasing blood lactate concentration. Reductions in blood flow to muscles will occur when arterial blood pressure is exceeded by intramuscular pressure. Edwards et al. (1972) reported reductions in muscle blood flow at isometric actions of the quadriceps muscles of as little during 25% MVC. Blood flow was totally occluded at 70% MVC. A further consequence of isometric actions of greater than 25-30% MVC is a reduced venous return. This would diminish end-diastolic volume and consequently cardiac output. Dynamic exercise may also periodically hinder blood flow but can be prolonged if exercise is at low percent of MVC. The ability to sustain dynamic actions has been shown to be dependent on the work to rest ratio (Asmussen, 1973).

The metabolic responses to submaximal high intensity exercise, such as in running, may be a better predictor of endurance performance than the VO_2 max. There is a curvilinear relationship between blood lactate concentration and work intensity (Brooks, 1985; Jacobs, 1986), with lactate concentration increasing exponentially as work load increases. In well-trained endurance athletes the curve is shifted to the right. Trained marathon runners have lower blood lactate levels than untrained runners at the same submaximal work intensity, but produce higher lactate concentrations at maximal loads. Sjodin and Jacobs (1981) found a positive relationship between the onset of blood lactate accumulation (OBLA) and marathon running performance.

The OBLA is represented by an inflection in the lactate-work intensity curve: it has also been referred to as the "anaerobic threshold" or lactate threshold. There has been disagreement as to the appropriateness of the term anaerobic threshold which Brooks and Fahey (1984) referred to as a misnomer. The preferred term is OBLA which describes the exercise intensity at which blood lactate concentration reaches 4 $mmol.l^{-1}$. The work-intensity corresponding to a reference lactate level can be used as an index of fitness. However, the absolute level of blood lactate produced is thought to reflect metabolic acidosis resulting from an increase in anaerobic glycolysis. The absolute blood lactate concentration can therefore be used as an index of the anaerobic stress induced by an exercise, particularly those including static and dynamic elements which may occlude blood flow to the working muscles. Circuit weight-training (CWT) utilise both types of muscular action, so measurements of heart rate or oxygen uptake alone are insufficient to determine the relative metabolic and circulatory loading of the anaerobic and aerobic components (Section 6.4).

3.2 ELECTROMYOGRAPHY

Electromyography (EMG) is the investigation of muscle function and coordination by analysis of the electrical activity generated by muscular action. Its uses have included the study of normal muscle function; muscle activity in sports, rehabilitation; isometric and dynamic muscle action; evaluation of functional anatomical movement; co-ordination and synchronisation of movement; specificity and efficiency of training methods; the relationship between EMG and force; the human-machine interface; and fatigue.

The origin of the EMG signal is the depolarisation and repolarisation of the sarcolemma of the muscle fibre which causes a change in electrical potential within the muscle. Depolarisation occurs in both directions along the muscle fibre away from the motor point (the site of innervation of the fibre). The potential change recorded from a single muscle fibre is referred to as a motor action potential (MAP). This can only be detected using micro-electrode techniques.

Three different types of electrodes may be used in EMG studies: surface electrodes, wire electrodes and needle electrodes. The use of surface electrodes limits research to the study of superficial muscles groups. Surface electrodes are appropriate when studying function in the large superficial muscle groups engaged in running as many muscle fibres are innervated by a single motor nerve and its branches.

Surface electrodes can be affected by artifacts caused by the movement of the skin and underlying muscle. Subcutaneous adipose tissue will attenuate the signal from the muscle. Both of these problems are reduced when using surface electrodes on endurance athletes (such as distance runners) as they have defined muscles and low adipose tissue or fat depots. Skin impedance may be reduced by removing the dead epithelial cells and oil by light abrasion with sand paper.

There is no standard method of electrode placement though a number of methods currently exist: i) The electrodes can be placed over the anatomical motor point of the muscle, where the number of neuromuscular junctions is highest; ii) The motor point can be located via electrical stimulation. The area producing the highest twitch for the least stimulation is defined as the motor point and the electrodes can be placed over this area. iii) The electrodes can be placed over the centre of innervation of the muscle and the distal tendon over the belly of the muscle. iv) The electrodes can be placed longitudinally over the centre of the muscle belly (Basmajian and Deluca, 1985; McClay et al., 1990). The last technique, recommended by the International Society for Electrophysiological Kinesiology (ISEK), found to be the most reliable (Dainty and Norman, 1987) will be used in this study.

Motor units are the single smallest controllable muscular unit and consist of an alpha motor neurone, the neuromuscular junction and the muscle fibres it innervates. Recording electrodes attached to the skin surface detect changes in voltage or potential caused by activation of motor units in the underlying muscle. The observed EMG signal is referred to as a motor unit action potential (MUAP) and is the recorded voltage difference between a signal and a reference electrode. The MUAP is the spatio-temporal summation of action potentials originating in individual muscle fibres (Dainty and Norman, 1987). A repetitive sequence of MUAPs, representing the temporal and sequential activity of gross muscle action, constitutes the myoelectric signal (MES) is referred to as a motor unit action potential train and is only suitable for visual inspection (Lagasse, 1987).

The MES can be processed in a number of ways in order to quantify the raw signal. The raw MES can be rectified to create onnly positive signals. Linear full-wave rectification is the basis for most quantification procedures. The negative portion of the MES is inverted to create an absolute positive value. Alternatively half-wave rectification may be performed in which the negative portion of the MES is eliminated.

After rectification the MES is usually filtered to smooth the raw signal removing large fluctuations produced by high frequency components. The processed signal, known as the linear envelope MES, follows the trend of the EMG signal and represents a clear and easily understood indication of muscular activity (Winter, 1979).

The next level of complexity of analysis is to average (integrate) the area under the linear envelope. This may be a cumulative average or reset when a predetermined voltage or time is reached. The frequency of resets indicates the amount of muscular activity. The process of integrating removes large fluctuations in the raw MES. The signal is usually integrated and averaged over a number of samples. It is then referred to as the 'average', 'mean ' or 'ensemble average' (Winter, 1979). To compare myoelectric signals obtained over period of time a moving average is used. A time 'window' is defined in which the average rectified MES is calculated and compared to that found in a later time 'window'.

Various normalisation techniques have been adopted in an attempt to allow comparison of myoelectric signals by reference to a pre-determined norm. The method commonly chosen is normalising to the EMG signal produced during a maximal isometric muscle action. More recently normalisation to the maximal signal amplitude (raw or rectified) in dynamic activity has been used, as greater amplitudes have been observed in dynamic than in isometric efforts (Cabri, 1989).

Yang and Winter (1984) examined the effect of four amplitude normalisation methods on inter-subject variability of EMG profiles in normal gait. Linear envelope EMG patterns collected over at least six strides were averaged. The average was then normalised to four reference procedures: a) the average MES over 3 50% isometric voluntary actions; b) the MES per unit isometric moment force; c) the peak of the linear envelope average; d) the mean of the linear envelope average. Methods a) and b) were derived from isometric calibrations and methods c) and d) from walking trials.

Analysis by coefficient of variation revealed the normalisation to either the peak or the mean of the linear envelope average reduced inter-subject variability, by 12%-73%. Normalisation using the average MES during 50% MVC or to the MES per unit isometric moment increased inter-subject variability. Yang and Winter (1984) concluded that the reduction of inter-subject variability in EMG studies was possible by appropriate amplitude normalisation. Therefore the sensitivity of surface EMG as a diagnostic tool in gait analysis could be increased. Normalisation to peak or mean of the linear envelope average is easy to implement and needs no additional data collection time. This technique may be preferable to normalising to maximal voluntary contraction. The relationship between iEMG and force has been reviewed by Cabri. (1989). In general, iEMG has been shown to increases linearly with muscle force in static muscle actions. The relationship between iEMG and force in dynamic actions is more complicated due to changes in joint angle and muscle length.

In normal dynamic muscle activity, such as running, isolated concentric and eccentric muscle actions rarely occur. Concentric and eccentric actions occur in combination, in the form of a stretch-shortening cycle (Norman and Komi, 1979), during which a muscle is lengthened (stretched) whilst its antagonist contracts. The result of this mechanism is a pre-stretch of the muscle prior to shortening, which reflexly increases the force of contraction. After exhaustive stretch-shortening cycle arm exercise, on a specially constructed sledge, an increase in iEMG activity, higher impact force and a lengthened hand contacted time has been reported (Komi, 1992). It was suggested that the muscle had altered its 'stiffness' regulation which had reduced its ability to absorb shock. Similar findings may be expected in leg muscles fatigued by marathon running, (Section 6.3) which may reduce the ability of the muscles to attenuate spinal loading. This will be examined in the present study.

3.3 PERCEPTUAL INDICES OF LOADING

The perceptual responses to a task can be quantified by rating the magnitude of the response on an appropriate scale. The four rating scale methods most commonly used are: the acceptability rating; the rating or ordinal scale; the category or interval rating scale; and the ratio scale. Such measures complement information gained from physiological and physical responses to a task. Psychophysical ratings of lifting acceptability have been used to assess the tolerable limits of lifting for individuals involved in heavy work tasks. They include the following tests: maximal isometric lifting strength (MILS) (Keyserling at el., 1980); the rate of acceptable lifting (RAL) (Snook, 1978; Griffin et al., 1984); and the acceptable isometric lifting frequency (AILF) (Troup et al., 1987). Whilst they have ergonomics applications they are not appropriate to this study. What is required is assessment of the subjective responses to the effort and perceptual responses to pain and exertion in running and circuit-weight-training.

The scale most frequently used to quantify effort in occupational and exercise contexts is the rating of perceived exertion (RPE) devised by Borg (1970). The RPE scale values range from 6 - 20, are used to denote heart rates from 60-200 beats.min^{-1} and are linked to verbal descriptors of intensity (Appendix 4). This category scale is linearly related to work rate, heart rate and oxygen consumption (Borg, 1982). The RPE can therefore be used to assess the individual's subjective perception of the severity of the exercise load. The scale can also be modified into a category scale with ratio properties to rate subjective feelings of pain or local muscular fatigue (Borg, 1982). Corlett and Bishop (1976) used a 7-point analogue scale from "extremely comfortable" to "extremely uncomfortable" to assess postural stress. This scale was modified into a visual-analogue scale with discomfort ratings between 0-100 by Troup et al. (1985). Kilbom et al. (1983) estimated discomfort of work using a 5 point analogue scale, (from 0 = no pain to 5 = intolerable pain).

Borg (1982) recommended the use of the RPE scale for determining the perceptual intensity of an exercise and the modified category scale for determining other subjective symptoms (e.g. breathing difficulties, aches and pains). In the present study the RPE scale is used to determine the overall exertion perceived by participants in running and CWT. An 11 point category scale with '0' representing no pain and '10' the worst pain imaginable was devised to rate low-back pain induced by the exercises (Appendix 4).

3.4 SPINAL SHRINKAGE AND SPINAL LOADING: A REVIEW OF EXPERIMENTAL WORK

3.4.1 SPINAL SHRINKAGE: A HISTORICAL PERSPECTIVE

It was De Puky (1935) who first drew attention to the role of the intervertebral disc in the oscillation of body length. Although De Puky (1935) claimed to have used a "very accurate scale" which would measure to a fraction of a millimetre, no details of his apparatus or methodology were given so the validity of this technique cannot be assessed.

De Puky (1935) stated that the pressure of body weight on the intervertebral discs caused them to flatten and resulted in the human being smaller in the evening than the morning. He also suggested that stature would be greater after lying down than after walking a long distance, and that the difference in stature would be more pronounced if a load were carried whilst walking. This implied that changes in stature were in some way related to the load on the spine.

De Puky (1935) measured the stature of a heterogeneous sample of men, women, young and old (n=1216) on rising from bed, at midday and before returning to bed. The mean change in stature for the subjects was 15.7 mm; 17.1 mm for males and 14.2 mm for females. When expressed as a percentage of body height these values are 1.02%, 1.16%, and 0.88% respectively. These values appear to be reliable as they correspond closely with the results of later research using specialised and validated stadiometry techniques (Tyrrell et al., 1985; Wilby et al., 1987).

De Puky (1935) proposed that the daily changes in stature were the result of increases in the normal physiological curves of the spine, due to disc compression resulting from fluid lost from the intervertebral disc during the course of the day. Fitzgerald (1972) showed greater height loss occurred in the morning than in the afternoon. This pattern is now known to be a characteristic diurnal change in stature following the investigations by Tyrrell et al. (1985) and Wilby et al. (1987).

De Puky (1935) found daily oscillations in stature altered with age. The greatest changes occurred in the second decade of life, followed by the fourth and third decades, with the smaller variation in the under 10 and over 50 year olds. However, great variation was observed within the decade boundaries and it is not known how many subjects were in each group. These findings were supported by Fitzgerald (1972) in 52 men aged 20-68 years, during a nine hour period of normal daily activity. Stature losses ranged from 1.8 mm in a 64 year old man to 23.4 mm in a 22 year old. In general stature losses decreased with age.

De Puky (1935) contended that the thickness of the intervertebral discs was inversely proportional to age. Therefore the compressibility of the discs would reduce with age, resulting in smaller changes in stature. De Puky (1935) reported that the proportion of the intervertebral disc in relation to the vertebral body decreases from 100% at birth, to about 50% at the age of 10 and less than 25% at 60 years and continues to decrease. The decrease in ratio of disc height to vertebral body height with age, paralleled the reduced diurnal change in stature observed with age. This reasoning was supported by Fitzgerald (1972), who found variation in daily body length to be dependent on age and height.

De Puky (1935) observed differences in diurnal change in stature between men and women and between 20 and 40 years, with men showing greater height loss. This was attributed to the greater amount of physical work physical work done by men. Results from later studies corroborate his findings of greater shrinkage associated with an increase in workload (Eklund and Corlett, 1984; Tyrrell et al., 1985).

Changes in stature are deemed to arise exclusively as a result of changes in spinal length since no changes occur in the long bones of the leg (De Puky, 1935; NASA, 1978). Fitzgerald (1972) considered that compression of the soles of the feet was a negligible source of height loss as equilibrium is reached rapidly on weight bearing. Foreman (1989) demonstrated that heel compression (an average of 4.4 mm) takes approximately 90 s to reach equilibrium. This must be taken into account when measuring changes in stature. It can be assumed that considerable changes in spinal length occur with loading and such changes would be refleected in alterations in stature. However, the use of changes in stature require accurate and reliable measurement.

3.4.2 METHODS OF CONTROLLING POSTURE WHEN MEASURING SPINAL SHRINKAGE

De Puky (1935) introduced the concept of controlling posture in order to obtain reproducible and reliable measures of Hstature. When he measured stature, the positions of the subject's heels and toes were controlled and the subject was asked to "straighten up" completely. The physiological curves of the spine were not controlled and changes in these would influence measures of stature. Methods of controlling spinal curvature were developed by subsequent researchers (Fitzgerald, 1972; Eklund and Corlett 1984; Reilly et al., 1934; Karg et al., 1985).

The apparatus used by Fitzgerald (1972) restricted movement of the subject by keeping posture constant during the measurements. Heel and toe positions were controlled. Microswitches linked to lights, were attached to a frame against which stature changes to be measured were indicated when posture was correctly aligned. This occurred only when lights indicating the correct positions of the skull, thoracic spine, sacrum, heels and deltoid prominence were illuminated. The eye line and apical contour of the cranium were controlled by a microswitch and fixed sighting scope visible to both experimenter and subject.

Intra-subject reliability was determined by demonstrating that five consecutive measurements could be performed with a spread of less than 0.3 mm. Only 8 of 60 subjects failed to produce reliable measures because they could not effectively control their posture.

Further improvements to this technique have been made by subsequent researchers (Eklund and Corlett, 1984; Reilly et al., 1984; Boocock et al., 1986). A stadiometer was developed (Plate 1), in collaboration between the University of Nottingham and Linkoping University (Sweden), and between Liverpool Polytechnic and the Royal Liverpool Hospital, with which it was possible to control variables which may affect the validity of measurements of change in stature. This has led to the study of the implications of spinal loading in industrial settings, during nursing activities and exercise.

The development of the stadiometer enabled researchers to control for the following variables: weight distribution between the soles and heels; angle between the feet; back, abdominal, shoulder and thigh muscle tension; head angle; and breathing cycle (Boocock et al., 1986).

Activity prior to measurement must also be controlled as this could affect shrinkage responses to any task under observation. In order to ensure that the data were reliably and accurately recorded, subjects were required to undergo a training period during which they had to produce 10 successive measurements of stature, with a standard deviation of less than 0.5 mm. Eklund and Corlett (1984) reported a standard deviation of 0.63 mm. Tyrrell et al. (1985) found the standard deviation of the training session measurements to be 0.6 mm over 10 readings. Leatt et al. (1986) found that three training sessions were required during which an average of 90 measurements were taken. Eklund (1986) during a field study investigating loading in female factory workers, found it possible to train subjects in a 30 min training session. The technique of stadiometry used was accurate and reliable, and could be performed with a limited period of preparation, which in terms of both time and achievability, was not prohibitive for the subjects.

An alternative method of producing reliable and repeatable measures of stature using a body caliper was developed by Krag et al. (1990). This technique relied upon a 4 inch (10 cm) wide plaster cast, pre-moulded to the contours of the spine, from the head to the sacrum, to maintain the correct posture. The hips were flexed at 0^{o} and the knees at 90 degrees. An aluminium bar with a steel rule was suspended over the subject. Measurements were made by positioning two vertical arms over the vertex of the cranium and the distal surface of the medial femoral condyles, whilst the subjects were recumbent. This eliminated errors due to heel compression.

Experimental error due to repositioning the caliper was given as 0.74 mm. A larger error of 1.98 mm was due to repositioning of the subject on the rig. It would appear from this that this technique is less accurate than that previously described by Eklund and Corlett (1984) and Boocock et al. (1986).

Magnusson et al. (1990) measured time dependant height loss during unsupported sitting. The rig used was similar to that described by Eklund and Corlett (1984), except that measurement were made continuously whilst the subjects were seated. A repeated measures test over five trials showed no systematic variation between measurements.

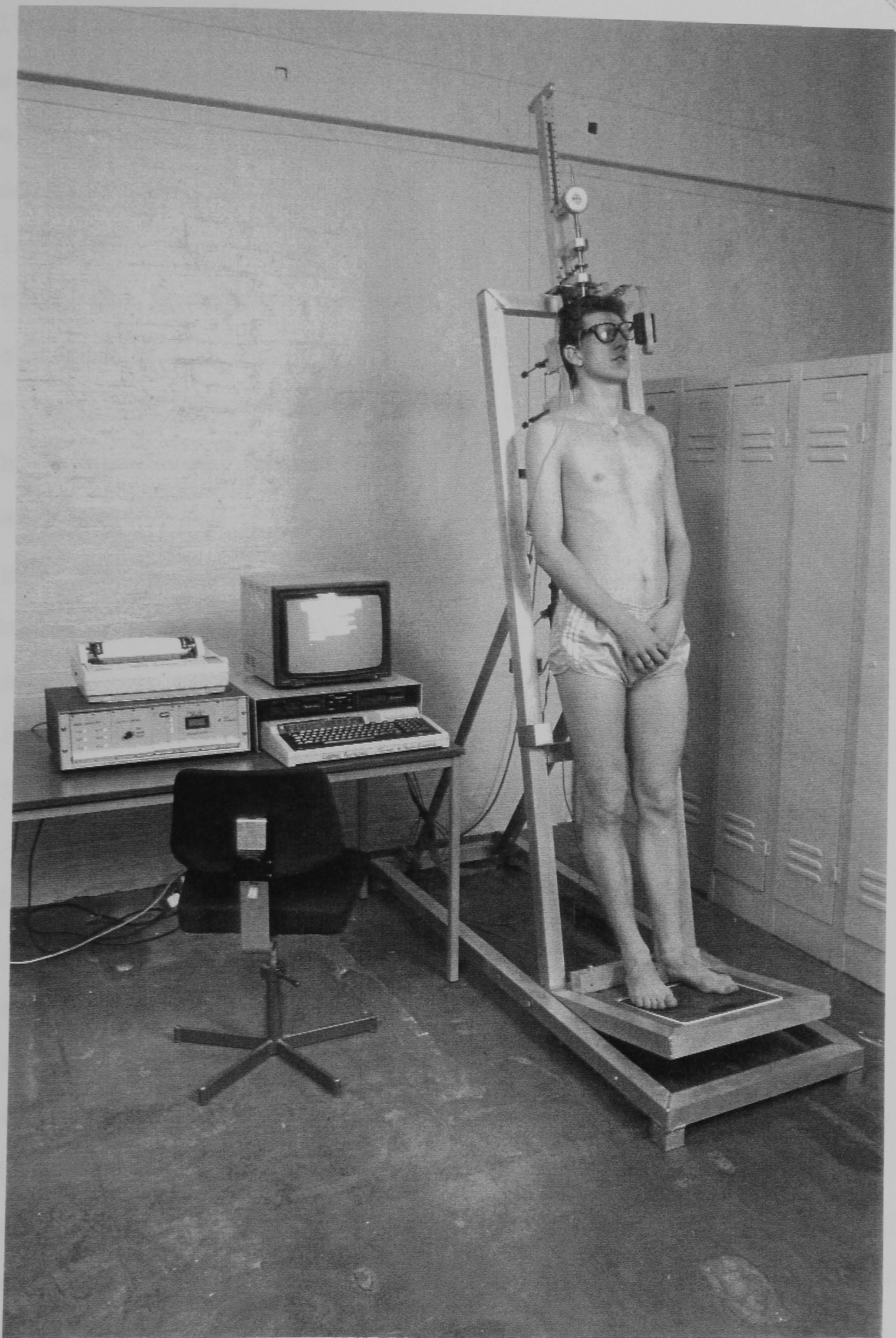


Plate 1. The stadiometer used for measuring changes in stature in the present study.

Althof et al. (1991) and Burton and Tillotson (1991) measured changes in stature using a stadiometer similar to that used by Eklund and Corlett (1984). The rig was modified so that stature measures were taken to a 'landmark' 1.5 cm superior to the vertebra prominens. Prior to the test measurements subjects were asked to walk about the laboratory, during which time measurements of stature were taken every 3 min. After a minimum of three measures, an exponential function was fitted to the data points (a linear function was sometimes used when appropriate). This period lasted between 25 and 40 min. During the subsequent test period measurements of stature were taken every 5 min. A second exponential curve was fitted to the data set. Change in stature was the difference between the two exponentials.

The method used by Althof et al. (1991) and Burton and Tillotson (1991) dispenses with the training of subjects using the stadiometer, included by previous authors (Eklund and Corlett, 1984; Reilly et al., 1985) to ensure reliability of the data. Nor does the method control for the effects of spinal loading prior to testing, which could affect spinal responses to loading. This technique may underestimate change in stature as the contribution from the cervical spine is omitted. This may be a significant ommission (Adams et al. 1987; Section 2.1.3).

3.4.3 DIURNAL VARIATION IN STATURE

All shrinkage studies adopt a repeated measures design, therefore it is necessary to control for diurnal variation in stature (which will affect responses to loading) by taking all measurements at the same time of day. Reilly et al. (1984) showed a 1.1% (19.3 mm) diurnal variation in body length in men aged 19-21 years. Most of the shrinkage was demonstrated to occur early in the day. On average 54% of the loss occurred during the first hour and 80% within 3 h of waking. Also, 71% of height regained at night occurred within the first half of the night's sleep. Similar figures were obtained in females aged 20-30 years by Wilby et al. (1987) who found a mean peak to trough variation of 0.92% of stature (15.4 mm). They also supported the finding that most stature was lost in the early part of the day and regained during the early part of sleep; 45% of loss in stature occurred within the first 90 min of waking and 71% of height lost was regained in the first half of the night's sleep. Krag et al. (1990) found a 16.4 mm loss in stature (0.9% of body height) following 8 hours of standing or sitting whilst performing sedentary activities, 13.6 mm of which was regained after 4 hours recumbency. These findings verify the claims of De Puky (1935).

Foreman and Troup (1987) used spinal shrinkage to examine the effects of diurnal variation on spinal loading during nursing activities. Four male nurses, aged 19-23 years, and eight female nurses, aged 22-24 years acted as subjects. Stature loss was measured over "early" (07:45-16:30 hours) and "late" (11:30-20:30 hours) nursing shifts of 8.75 hours and 9 hours duration, respectively. This was compared with shrinkage during a 12.5 h period on a day off work. No significant differences were found in shrinkage between early and late shifts:- 10.2 mm and 9.8 mm respectively. Shrinkage during the day-off (8.14 mm) was significantly less than on either of the shifts. This indicated that the workload, induce by nursing activities loaded the spine to a greater extent than was experienced during time off-work. The inference could be made that if shrinkage were reduced in nursing to levels acquired during the day-off, the risk of low-back pain would be reduced. Measurements of spinal shrinkage may be an appropriate tool with which to determine the effects of ergonomics intervention aimed at reducing spinal loading in nursing.

3.4.4 THE EFFECTS OF STATIC LOADING AND DYNAMIC LIFTING ON SPINAL SHRINKAGE

It has been shown that changes in stature can be used to investigate spinal responses to loading. Studies using measurements of spinal shrinkage have investigated the effects of the following factors on change in stature: diurnal variation in stature (Reilly et al., 1984;

Tyrrell et al., 1985); chair design and seated task performance (Eklund and Corlett, 1984; Eklund and Corlett, 1987); circuit weight-training (Leatt et al., 1986; Wilby et al., 1987); running (Leatt et al., 1986; Reilly et al., 1987); and the effects of standing, lying, Fowler's position and gravity facilitated traction (inversion) on unloading the spine (Eklund and Corlett, 1984; Tyrrell et al., 1987; Boocock et al., 1988).

The amount of shrinkage in a given time can be taken as a reflection of the load occurring throughout that period. Changes in shrinkage above or below the norm during this period would reflect changes in the load on the spine brought about by the activity performed.

Investigations using shoulder loading techniques have demonstrated that the normal rate of diurnal variation in stature is increased by physical activity. Eklund and Corlett (1984) showed that carrying a 14 kg shoulder load during office work for 1 h increased shrinkage from 1.4 mm to 3.2 mm at the same time of day. Carrying a 14 kg load in one hand for half an hour produced 2.8 mm of shrinkage. Tyrrell et al. (1985) demonstrated that when carrying a rucksack or a barbell shrinkage was in proportion to the magnitude of the weight carried. For example, loads of 2.5 kg, and 10 kg carried in a rucksack for a 20 min period elicited 3.87 mm and 5.45 mm shrinkage, respectively. A 10 kg load on a barbell across the shoulders produced similar shrinkage (5.14 mm) to the 10 kg load in the rucksack. Barbells of increasing weight (20 kg, 30 kg and 40 kg) carried for 20 min caused 7.11 mm, 9.42 mm and 11.22 mm respectively. The rate of shrinkage also increased with the increase in load.

Tyrrell et al. (1985) also established that repetitive lifting caused greater shrinkage than static loading when the same weight was used. A 10 kg barbell lifted 12 times per minute for 20 min produced 6.9 mm shrinkage compared, with 5.14 mm for a static load. A 40 kg barbell lifted at the same cadence produced shrinkage of 14.49 mm compared with 11.22 mm for the static load.

3.4.5 ERGONOMICS INVESTIGATIONS USING SPINAL SHRINKAGE

The first empirical study using changes in stature was a study of aviation ergonomics by Fitzgerald (1972). It was shown that shoulder loading caused greater than normal stature changes in 32 RAF aircrew. The amount of stature loss was significantly related to the mass of the shoulder load. A 2.3 kg load caused less shrinkage than a 10 kg load.

Another study showed that astronauts may increase in stature by 3% of total body height (about 5 cm) during the first 48 hours of weightlessness (NASA, 1978). The authors noted the implications of spinal shrinkage for all human-machine interfaces, such as working in pressure suits and control stations. In this latter report experimental procedures were not sufficiently well documented to allow confidence in the data.

Eklund and Corlett (1987) used shrinkage to evaluate the effect of chair design on spinal loading at five different work stations over a 45 min period (Table 4). Significant differences in spinal shrinkage were observed between subjects when using different chairs in two of the tasks. This indicated that choice of chair design would be critical in reducing spinal loading in these particular tasks. Further work on seat design was carried out by Ericson and Goldie (1989) who demonstrated that eight subjects (3 female and 5 male; aged 30.5 years), showed decreased shrinkage (1.3 mm) in a conventional chair when compared to two modified chairs, the Ullman and the Balans chairs, over a three hour period. These chairs were reportedly designed to reduce the stress on the back but caused 1.8 mm and 3.1 mm of shrinkage, respectively. These findings emphasised the usefulness of using shrinkage measures as a means of evaluating the effects of physical activity on spinal loading.

Magnusson et al. (1990) measured change in stature during 5 min sitting in 15 female subjects. Five subjects were from each of the following age rages: 20-25, 40-45 and 60-65 years. Subjects were recumbent for 30 min prior to measurement. Measurements took place 30 s after rising from the chair. The mean shrinkage observed was 4.53 (+2.29) mm. The shrinkage for the age groups was 3.85 (+2.04) mm, 3.46 (+1.41) mm and 6.28 (+2.40) mm for the 20-25, 40-45 and 60-65 year olds respectively. There was a significant difference in shrinkage between the two older groups which may represent the effect of age related spinal changes, in agreement with data from cadaver studies (Twomey and Taylor, 1991) .

The shrinkage observed in this study is high for such a short duration of loading. It may reflect the pre-loaded state of the discs induced by the 30 min period of recumbency prior to testing. The finding also contradicts those of Althof et al. (1992) who found that sitting invariably leads to an increase in stature. They examined the effects of eight seats, with and without back rests, on stature and invariably found increases of between 1 and 4.2 mm. The findings of Magnusson et al. (1990) support those of Ericson and Goldie (1989).

The assertion that sitting increases spinal loading would until now have been uncontroversial as losses were assumed to be attributable to the increased intradiscal pressure found when sitting (Nachemson and Elfstrom, 1970). The load on the spine is dissipated not solely by the discs but also by the posterior elements, ligaments and muscles. The load on each element is dependent on posture (Section 2.1.3). Changes in stature reflect the load on the whole spine and not just L3/L4 discs, as in the case of disc pressure measurements. Therefore, the posture adopted is critical to the response of the spine when subjected to loading.

Table 4. Spinal shrinkage industrial tasks.

		SPINAL SHRINKAGE (mm)
FORWARD PUSHING TASK:		
	Low backrest chair	1.37
	High backrest chair	0.66*
LIGHT ASSEMBLY TASK:		
	Conventional seat	2.41
	Sit-stand seat	0.93*
VISION TO ONE SIDE:		
	Low backrest chair	0.88
	High back rest chair	1.44
PUNCH PRESS WORK:		
	Conventional seat	-0.19
	Sit-stand seat	-0.48
GRINDING FORCE TASK:		
	Low backrest chair	2.81
	High back rest chair	2.54

(Adapted from Eklund and Corlett, 1987) *(P<0.05)

The studies by Eklund and Corlett (1987), Magnusson et al. (1990) and Althof et al. (1992) all used different techniques to monitor stature, although each group did use a method of controlling posture and produced repeatable measurements. The individual differences between the results of the studies may partially be attributable to differences in experimental procedures.

Driving a motor vehicle was identified as a risk factor in the development of low-back pain by Troup (1978). The effect of driving a car on spinal shrinkage was examined by Amin et al. (1988). Driving with a seat belt whilst subjected to sinusoidal vibration at 4 Hz. 1 ms^{-1}, was compared with driving without a seat belt and simultaneously subjected to vibration, and to driving with a seat belt whilst subjected to vibration preceded by 45 min in Fowler's position. Fowlers's position, used by physiotherapists to treat patients with low-back pain, requires subjects to lie on their backs, the hip and knee joints flexed 90°, with the lower leg supported on a chair. The overall increases in stature in 6 female subjects aged 20-25 years were 1.68 (0.79) mm, 0.96 (0.50) mm, and 2.27 (1.6) mm, respectively. The results suggest that the spine was unloaded in each condition although no statistical analysis was carried out on the data. Unloading was greatest following Fowlers' position, though the duration of this benefit was not documented.

The findings of Althof et al. (1992) support this data. They demonstrated that sinusoidal vibrations of 10 Hz. 1 ms^{-1}, 5 Hz. 0.55 ms^{-1} and 5 Hz. 1.5 ms^{-1} all caused an increase in stature of around 1.5-2.0 mm. This was not significantly different to that found in unsupported relaxed sitting.

Burton and Tillotson, (1992) examined the effect of a simulated overhead working posture (bolt tightening) and an ergonomics intervention, (bolt tightening at chest height) on spinal shrinkage. Observed decreases in stature were small and not significantly different between the conditions. Significant differences were found between both the degree of lumbar extension and the level of perceived exertion which were higher in the overhead condition.

This experiment demonstrated the benefit of an ergonomics approach to the study of spinal loading. Although spinal shrinkage was unaffected by the change in posture, possibly because of the posterior elements taking some of the load, perceptual responses were more sensitive to changes of load. The stadiomentry technique used in this study omitted measurement of cervical shrinkage and may therefore be less sensitive to diffences in spinal loading.

Stalhammer et al. (1992) examined the effect of self-paced and force-paced lifting work on spinal shrinkage using the device described by Eklund and Corlett (1984). The subjects were 5 men and 5 women who selected the weight to be lifted by the rate of acceptable lifting (RAL) method (Griffin et al., 1984). The weight chosen to be lifted was on average 7.5 kg for the women and 11.5 kg for the men. The weight in a 30x30x30 cm box was lifted from a 10 cm shelf to knuckle height for 30 min. The weight was lifted at a forced pace 4 times per minute.

Spinal shrinkage was 5.1 (+2.0) mm and 5.8 (+2.3) mm for the self-paced lifts in the female subjects and 5.8 (+1.2) and 6.8 (+2.2) mm for the male subjects. The differences were not significant between paces or sexes, despite the men lifting a greater mass. This may be due to the lower lift rate chosen by the men during the self pace work.

Other authors have used spinal shrinkage to study spinal loading in chair design, vibration and postural changes. Their procedures either fail to control the posture of the subject or do not provide measurement repeatability data (Strickland and Shearin (1972); Karg et al., 1985; Klingenstierna and Pope, 1987; Bendix et al., 1988). The need for such methods of control when measuring changes in stature were explained in Section 3.4.2. The reliability of data obtained without adequate control is questionable.

3.4.6 SPINAL SHRINKAGE IN EXERCISE CONTEXTS.

3.4.6.1 SPINAL SHRINKAGE DURING CIRCUIT WEIGHT-TRAINING

Circuit weight-training (CWT) is a mode of exercise chosen by athletes to improve muscular strength and endurance, body composition and cardiovascular fitness (McArdle et al., 1991). A circuit usually consists of 8-15 exercises, using alternating body parts to avoid local muscular fatigue. The training stimulus is achieved by lifting weights of between 40-55% of 1 RM for up to 30 s, with no more than 30 s rest between exercises. The duration of the circuit should not normally be less than 20 min.

Lifting in industry and weight-lifting in sports training have been associated with a high incidence of lower back problems (Troup and Edwards, 1985; Williams, 1980). Information on the load imposed on the spine by CWT may allow the identification and avoidance of harmful practices. This in turn may and lead to alterations in training patterns and reduce the incidence of back injuries during CWT.

Leatt et al. (1986) studied the effect of CWT on spinal shrinkage. In a CWT session of 25 min duration, 5.62 mm of shrinkage occurred. Circadian variation in responses to CWT of females were found by Wilby et al. (1987) to be of a similar magnitude. It was shown that the effects of spinal loading were dependent on the time of day and were more prominent in the morning when the disc height was greatest as a result of unloading during sleep. Wilby et al. (1987) demonstrated that circuit weight-training caused 22% more shrinkage in the morning than the same circuit performed in the evening, 5.4 mm and 4.3 mm, respectively. The amount of shrinkage observed during CWT was similar to that in carrying a static shoulder load for 20 min (5.14 mm) reported earlier by Tyrrell et al. 1985. This represents approximately 25% of the expected diurnal variation in stature (Leatt et al., 1986; Wilby et al., 1987). However, the exercises in the circuits devised by Leatt and Wilby were deliberately selected to load the spine directly or to use the muscles of the back, which is not normally the case during CWT.

A weightlifting belt is commonly used by weight and power lifters to support and stabilise the spine. Bourne and Reilly (1991) investigated the effect of wearing a weightlifting belt on spinal shrinkage during circuit weight-training. A circuit of six exercise performed three times caused 2.87 mm of shrinkage with the belt and 3.59 mm without the belt. Although this difference was not significant, less discomfort was perceived when the belt was worn. The degree of shrinkage was significantly correlated with perceived discomfort when no belt was worn. The lower amount of shrinkage found in this study, compared to Leatt et al. (1986) and Wilby et al. (1987) is possibly attributable to diurnal effects as the circuit was performed later in the day.

3.4.6.2 SPINAL SHRINKAGE DURING RUNNING

Running has also been found to increase spinal shrinkage beyond its normal rate. Leatt et al. (1986) compared spinal shrinkage in experienced and novice runners who ran at 12.2 $km.h^{-1}$ for 6 km, which took approximately 30 min. This caused 3.26 mm shrinkage in the novice runners and 2.35 mm in the experienced runners but the difference was not significant. The experienced runners then ran for a further 19 km at 14.7 $km.h^{-1}$ in 78 min causing a further 7.79 mm shrinkage. The total distance covered in 108 min was 25 km: the total shrinkage was 10.14 mm for the whole run. The runners also had to change their running speed from 12.2 $km.h^{-1}$ to 14.7 $km.h^{-1}$ over the distance of the run which may also have altered the shrinkage response. It is possible that the increase in pace would have increased the load on the spine but the effect of running speed on spinal shrinkage has yet to be established.

Leatt et al. (1986) suggested that glycogen depletion, and the resultant fatigue and reduced muscular control of gait, during a long run may affect shrinkage. Extrapolating their shrinkage results for the full marathon distance of 42.2 km, they predicted that shrinkage of about 17 mm would occur during a marathon race. Reilly et al. (1988) acknowledged that a linear extrapolation to a full marathon race is invalid because rate of shrinkage changes with time under conditions of constant loading. Consequently the rate of shrinkage is unknown over this distance of 42.2 km. The effects of running at such intensity and duration on spinal loading have yet to be determined.

Reilly et al. (1988) examined three extrinsic factors which could affect spinal shrinkage whilst running. These were:-the effect of the duration of running; the effect of interval running and steady-paced running when the distance covered remained constant; and the effect of running barefoot and in running shoes. Subjects were ten adults untrained in running, aged 19-26 years, each of whom undertook three 40 min treadmill runs: a steady pace of 10.2 $km.h^{-1}$ running barefoot; a steady pace run at 10.2 $km.h^{-1}$ wearing running shoes; and interval running, changing pace between 8 $km.h^{-1}$ and 15 $km.h^{-1}$ but covering the same distance as the other two runs. The mean stature losses were 5.2 mm, 4.52 mm and 5.69 mm respectively, which did not differ significantly. The lack of difference between barefoot and shod running was attributed an adaptation of stride pattern to reduce impact. The lack of difference between interval and steady pace running could have been due to a reduction in the rate of shrinkage during the slow phase of interval running compared with the rate at the faster speeds.

White and Malone (1990) examined the effect of a 9 mile run (14.4 km), at around 6 minute mile pace, on intervertebral disc height. A change in spinal length of 12 mm was measured, between C7 and S1, using a fibreglass tape. However, they failed to show the repeatability of this technique and did not control the posture of the subjects. Thus their results may have been invalidated.

3.4.6.3 SPINAL SHRINKAGE DURING PLYOMETRIC DRILLS

The effects of bounding activities (plyometrics) on spinal shrinkage have been examined by Boocock et al. (1988). Plyometrics are explosive exercises of short duration used to increase muscle power, by athletes and sportsmen competing in events requiring fast ballistic actions (e.g. basketball). They utilise the stretch-shortening characteristics of skeletal muscle. The muscle is loaded rapidly in such a way that it acts eccentrically followed immediately by a powerful concentric contraction.

Boocock et al. (1988) studied the effect of gravity inversion as a precursor to plyometric training to determine whether spinal shrinkage was attenuated. Fifty standing broad jumps, in sets of five with 15 s rest in between each set, were performed by eight male subjects, aged 20-26 years. The average duration of the exercise period was 6.7 min. The protocol was performed twice and preceded by either 10 min gravity inversion or 10 min standing. Plyometric bounding caused 3.49 mm and 1.69 mm shrinkage when preceded by gravity inversion and standing, respectively. The pre-exercise inversion period caused a significant increase in stature of 2.74 mm compared to 0.03 mm when standing. The degree of shrinkage following inversion suggested the benefits of unloading the spine prior to exercise were short lived.

Boocock et al. (1990) examined the effect of plyometric drop jumping on spinal shrinkage. Drop jumping is a method of training whereby an athlete drops from a box to the ground to induce an eccentric action in the extensor muscles of the legs. This is followed immediately by rebound jump, usually over a hurdle of a pre-determined target height. Eight male subjects aged 20-31 years undertook five sets of five drop jumps from a height of 1 m, followed by a rebound jump over a 0.5 m hurdle. To determine the effect of unloading the spine post-exercise the procedure was performed twice and was followed by either 20 min gravity inversion or 20 min standing. Drop jumping caused 1.81 mm and 1.68 mm shrinkage in the two sessions, respectively. Gravity inversion and post-exercise standing caused increases in stature of 5.18 mm and 0.76 mm. Each of the 20 min post-exercise periods were followed by a 40 min period of standing. During the period following inversion 4.07 mm stature was lost, and after 30 min there was no significant difference in stature between the two conditions. This indicated that the benefits of unloading the spine post-exercise were also short lived.

Fowler et al. (1991) examined the effects of drop-jumping from a 0.26 m height in eight male subjects aged 21.65 (1.76) years. A repeated measures design was used with the subjects assigned to two conditions: five sets of 10 drop jumps were performed, with 30 s rest between sets; and five sets of 10 drop jumps were performed, with 30 s rest between sets, whilst wearing a vest weighing 8.5 kg. The vertical forces for the jump were measured with a Kistler force platform on a separate occasion. The changes in stature for the loaded and unloaded condition were 0.62 (0.43) mm and 2.14 (1.56) mm respectively for the unloaded and loaded conditions ($p<0.005$).

The shrinkage data reported by Fowler et al. (1991) for the unloaded condition (0.62 mm) is about one third of the mean of the values reported by Boocock et al. (1990) (about 1.75 mm). This may be explained by the 50% reduction in drop height adopted by Fowler et al. (1991)

and the use of the rebound jump (and therefore a second impact landing) by Boocock et al. (1990). Both of these factors may have increased spinal loading.

The force platform data (Fowler et al., 1991) showed that the mean vertical reaction forces were 3.90 (0.66) and 4.11 (0.54) x body weight for the unloaded and loaded conditions, respectively. This study demonstrated that use of an external load while drop jumping caused an increase in the physical stress imposed, both in terms of spinal shrinkage and vertical reaction forces. Ground reaction forces in running are lower than in drop jumping, between 1.3 and 1.8 times body weight (Miller, 1990) depending on the speed of running. However, these forces are repetitive and have a cumulative effect as they are transmitted to the spine.

3.4.7 UNLOADING THE SPINE AND CHANGE IN STATURE

Boocock et al. (1988, 1990) demonstrated that the spine could be unloaded prior to and post-exercise, but found the effects of unloading to be transient (Section 3.4.6.3). Other authors have also used recovery postures post-exercise in an attempt to lessen the effects of spinal loading. Eklund and Corlett (1984) showed that the mean increase in stature after lying down was 7.3 mm in four subjects after 1.5 h. Also, shrinkage of 2.8 mm caused by carrying a 14 kg weight in one hand was recovered after 15 min lying.

Fowler's position (Section 3.4.5) is widely advocated for the relief of low-back pain. The efficacy of Fowler's position in unloading the spine was compared with standing by Tyrrell et al. (1985). Fowler's position was shown to produce significantly greater gains in stature than standing, although standing produced 60-80% regains. Following shoulder loading with a 10 kg barbell, stature increased 2.9 mm more in Fowler's position than during standing and after stoop lifting with a 10 kg barbell the difference was 3.6 mm. However, Leatt et al. (1986) found no recovery of stature on standing post-exercise after running and CWT .

Leatt et al. (1985) compared unloading the spine using Fowler's position with gravity inversion at 50^{o}, 70^{o} and 90^{o} for a 30 min period. The four conditions caused increases in stature of 3.58 mm, 5.57 mm, 4.39 mm and 4.57 mm, 50^{o} inversion showing the greatest gains. Each condition was followed by a period of 20 min standing. The effect of Fowler's position was lost during this time and the inversion procedures lost 74% of their average effect, indicating that the effects of this type of unloading on stature is transient.

3.4.8 MEASUREMENTS OF STATURE IN SUBJECTS WITH LOW-BACK PAIN

De Puky (1935) recognised the possibility of using change in stature to indicate spinal loading in subjects with low-back pain. He was unable to measure patients successfully because of their "defensive rigidity" in the muscles as a result of pain.

To date only one study has used measures of spinal shrinkage as a tool in the study of populations with low-back pain. Hindle et al. (1987), using the stadiometer developed by Eklund and Corlett, (1987) looked at diurnal variation in stature in back pain sufferers with ankylosing spondylitis. An eight hour period of normal daily activity caused a reduced amount of shrinkage among the test group when compared with normals, 0.34% (5.23 mm) and 0.68% (11.4 mm) of mean erect stature, respectively. These findings were true for patients having symptoms for under two years as well as those of longer duration. This suggested that the technique may be useful in the early detection of the disorder. It is possible that other pathologies affecting the back may also cause altered responses to loading.

Fitzgerald (1972) made the observation, in his study of diurnal changes in stature, that the subject with the least change in stature had a history of low-back pain, though no diagnosis was given. If correct, such observations offer the possibility of using measurements of shrinkage to screen for athletes at risk from low-back pain, by identification of abnormal responses to exercise induced spinal loading.

3.4.9 CHANGE IN STATURE AND PERCEPTUAL RESPONSE TO LOADING

Troup et al. (1985) postulated a correlation between perception of stress and spinal shrinkage during physical activity. It was hypothesised that if such a link existed it may have diagnostic significance in cases of low-back pain, the aetiology of which may include postural stress, overexertion and fatigue from repetitive loading.

Eight subjects were asked to wear a waistcoat with pockets containing lead weights for 45 min. The weights were evenly distributed about the chest and back. Four shoulder loads were applied 0, 10, 20 and 25 kg. Spinal shrinkage was shown to increase with the weight carried. Subjects were asked to report discomfort during load carriage on a visual-analogue scale, with discomfort ratings from 0 -100. A positive correlation was found between spinal shrinkage and perception of discomfort (r=0.91).

The relation between subjective states and change in spinal length have also been examined when stature is increased rather than reduced. Leatt et al. (1985) studied the effects of gravity inversion on unloading the spine (See section 6.7.4 for details) and demonstrated that when inverted at 50^{o} for 30 min there was a negative correlation between change in stature and ratings of comfort. That is, those subject who were feeling uncomfortable during inversion regained the least stature. It was also found that the more comfortable subjects maintained their height gain during a subsequent 20 min standing recovery period.

These findings led Troup et al. (1985) to conclude that adverse effects may stem from activities or postures perceived as uncomfortable. It was proposed that by increasing the skill or fitness of subjects, the "discomfort threshold" could be raised, thereby reducing the perception of discomfort during activity. The results of the correlation analysis indicated that a reduction in spinal shrinkage, and hence spinal loading, was coincident with reductions in perceptual stress.

Leatt et al. (1986) examined the relationship between spinal shrinkage and ratings of perceived exertion (RPE), during circuit weight-training (CWT) and running. Spinal shrinkage was unrelated to RPE in CWT, a finding confirmed by Wilby et al. (1987). Leatt et al. (1986)

found that perceived exertion was positively related to spinal shrinkage in novice runners, though not experienced runners and inversely related to the height regained after exercise.

Boocock et al. (1988) did not observe a significant relationship between spinal shrinkage and RPE during plyometric drills (depth jumping). However, Boocock et al. (1990) did find a correlation between RPE and spinal shrinkage during drop jumping. No correlation was found between low-back pain ratings and spinal shrinkage in either study as subjects were asymptomatic and did not report low-back pain during either protocol.

The evidence for a relationship between perceptual stress and spinal shrinkage is inconclusive. It would appear that perception of exertion during exercise is only loosely associated with spinal shrinkage, as it is largely an indication of perceptual responses to metabolic rather than physical loading (Borg, 1982). Perception of postural comfort may be more closely related to spinal shrinkage. Further evidence is required to determine the relationship between spinal shrinkage and perception of pain, as low-back pain was not experienced by subjects in the studies by Boocock et al. (1988, 1990).

It is recognised that heavy industrial work can precipitate the onset of low-back pain (Frymoyer et al., 1980; Pheasant, 1991). A parallel situation may arise in running and CWT which have been associated with lower back injury. If measurement of spinal shrinkage could identify excessive loading of the spine during these exercise regimens, they could subsequently be altered to reduce spinal loading.

Advances in techniques of stature measurement (Eklund and Corlett, 1984; Reilly et al. 1984; Boocock et al., 1986) have enabled investigators to identify differences in shrinkage in subjects with and without lower back problems (Hindle et al., (1987). Change in stature may prove to be an appropriate method of differentiating between symptomatic and asymptomatic athletes.

Methods of unloading the spine may be a useful adjunct to running and CWT if they can reduce the harmful effects of spinal loading. The warm-up and warm-down routines used by athletes as an adjunct to training, could have some beneficial effect in attenuating or reducing spinal shrinkage. Measurement of spinal shrinkage allow such routines, and other interventions to be evaluated.

4 AIMS AND OBJECTIVES

The investigative section of this thesis can be divided into three subsections: an epidemiology section; and experimental section; and an intervention section.

4.1 EPIDEMIOLOGY SECTION

The aim of the epidemiology section was to develop a profile of the marathon runner and weight-trainer: their training habits; injury rates, particularly low-back pain; their behaviour in response to injury prevention and treatment. Three surveys were carried out on distance runners and one on weight-trainers.

4.1.1 RUNNING SURVEY 1: A RETROSPECTIVE SURVEY OF INJURY PATTERNS AND TRAINING HABITS IN RECREATIONAL MARATHON RUNNERS

The aims of this part of the work were threefold: to examine the prevalence of low-back pain in marathon runners; to determine the relationship between extrinsic training variables and injury rate; to investigate the behaviour of marathon runners with respect to injury prevention.

4.1.2 RUNNING SURVEY 2: A RETROSPECTIVE SURVEY OF INJURY PATTERNS AND TRAINING HABITS IN CROSS COUNTRY RUNNERS

The aims of this survey were to: examine the prevalence of low back-pain, injury distance runners other than marathon runners; to determine the relationship between extrinsic training variables and injury rate; and to investigate the behaviour of the runners towards injury prevention. This would enable comparison between marathon runners and other distance runners (cross country runners) to be made.

4.1.3 RUNNING SURVEY 3. A RETROSPECTIVE AND LONGITUDINAL SURVEY OF INJURY PATTERNS AND TRAINING HABITS IN COMPETITION MARATHON RUNNERS

The aim of this part of the investigation was to determine the incidence of low-back pain in marathon runners and to determine whether this was affected by extrinsic training variables.

A retrospective survey (similar to that in 4.1.1) was used to determine the prevalence of low-back pain in club level marathon runners. This was followed by a longitudinal survey of the runners, during which training diaries were kept over a 10 month period. These were employed to provide data on the incidence of injury in the population and on possible extrinsic mechanisms which predispose towards injury. Once such factors are identified steps to prevent injury may be taken.

4.1.4 WEIGHT-TRAINING SURVEY: A SURVEY OF INJURIES AND ATTITUDES TOWARDS TRAINING IN WEIGHT-TRAINERS

The aim of this study is to examine the prevalence of low-back pain in weight-trainers at weight-training gymnasiums, by using retrospective questionnaires. Attitudes towards training and treatment of injury are also investigated.

4.2 EXPERIMENTAL SECTION

The relationship between running speed and spinal loading, measured by spinal shrinkage, and the difference in spinal shrinkage between runners suffering from chronic low-back pain and asymptomatic runners was investigated in this section.

4.2.1 EXPERIMENT 1: RUNNING SPEED AND SPINAL SHRINKAGE IN RUNNERS WITH AND WITHOUT LOW-BACK PAIN

Low-back pain in runners may be associated with abnormal rates of spinal shrinkage. This study aimed to:

i) investigated the effect of running speed on spinal shrinkage;

ii) compared changes in stature caused by running in subjects with and without low-back pain symptoms;

iii) determine the effects of age on spinal shrinkage in running.

It was hypothesised that:

i) running speed would affect the amount of shrinkage incurred in a run of fixed duration;

ii) spinal shrinkage would be greater in runners with a history of back pain symptoms;

iii) spinal shrinkage would be reduced in older runners.

4.2.2 EXPERIMENT 2: DIURNAL VARIATION IN STATURE IN SUBJECTS WITH SEVERE CHRONIC LOW-BACK PAIN.

It is possible that subjects with low-back pain show greater spinal shrinkage than asymptomatic patients. Studies of motion segments from cadavers have shown greater flexion creep deformation responses to compression in degenerated discs (Taylor and Twomey, 1980). The aim of this study was:- 1) to examine the diurnal variation in spinal shrinkage in patients with severe low-back pain and 2) to compare these values with those previously reported in the literature.

It was hypothesised that subjects with chronic low-back pain would exhibit greater shrinkage than asymptomatic subjects.

4.2.3 EXPERIMENT 3: THE EFFECT OF A LONG DISTANCE RUN ON SPINAL SHRINKAGE

The aims of this study were to:

i) determine the spinal shrinkage occurring in a run of marathon race distance;

ii) determine the relationship between EMG of the leg and back muscles and changes in stride rate during a run of marathon distance;

iii) investigate the relationships between physiological (heart rate, rectal temperature and volume of water consumed), physical (stride rate variations) and subjective (perception of effort and ratings of back pain) responses to a treadmill run to exhaustion at marathon race pace.

It was hypothesised that:

i) Spinal shrinkage over a run of the marathon distance, would be greater than that observed over runs of a shorter distance.

ii) Fatigue whilst treadmill running over the marathon distance would be indicated by an increased stride rate.

iii) Changes in gait due to muscle fatigue woukld be eviddent in increased amplitude of EMG signals, as neuromotor patterns in the muscles alter.

iv) Heart rate, rectal temperature and subjective responses to effort would increase during the run.

4.2.4 EXPERIMENT 4: PHYSIOLOGICAL AND SPINAL RESPONSES TO CIRCUIT WEIGHT-TRAINING (CWT)

Previous studies of the effects of CWT on spinal shrinkage have used exercise which deliberately loaded the spine. Two studies were designed using a CWT regimen mmore typical of that employed in aerobic training.

The aims of these studies were to:

i) determine the intensity of exercise during CWT by observing the physiological and perceptual responses to three consecutive circuits, and ascertain how responses vary between circuits;

ii) study the physical responses to CWT using spinal shrinkage as an indication of spinal loading, and relate this to the physiological and perceptual responses.

It was hypothesised that the physiological and perceptual responses to CWT would be correlated with spinal loading.

4.3 INTERVENTION SECTION

Warm-up and warm-down routines are often advocated to reduce injury risk associated with exercise. By establishing the effects of exercise on spinal loading, it may be possible to decrease the load on the spine by manipulating training regimens. This may reduce the risk of damage to the lower back. Spinal mobilization exercises, included as part of warm-up and warm-down regimens, may mitigate the effects of spinal loading, decrease disc stiffness and reduce injury risk.

This section was in two parts. It aim was to investigate whether pre- and post-exercise mobilization procedures could be influence the rate of spinal shrinkage in running and CWT.

4.3.1 INTERVENTION STUDY 1: AN EVALUATION OF WARM-UP AND WARM-DOWN, PROCEDURES BEFORE AND AFTER RUNNING, USING SPINAL SHRINKAGE

The aim of this study was to compare the effects of a modified McKenzie mobilisation procedure (McKenzie, 1980) and a conventional warm-up on shrinkage in stature incurred during a 20 min run and followed through the comparisons into the recovery period.

It was hypothesised that:

i) pre-exercise spinal mobilisation exercises would be attenuate spinal loading in the subsequent exercise compared to a conventional warm-up routine;

ii) post-exercise spinal mobilisation exercises would reverse spinal shrinkage at a greater rate than a conventional warm-down routine.

iii) The modified mobilisation procedure would elicit greater unloading effects than the conventional warm-up.

4.3.2 INTERVENTION STUDY 2: AN EVALUATION OF MOBILISATION PROCEDURES PRE- AND POST- CIRCUIT WEIGHT-TRAINING USING SPINAL SHRINKAGE.

This study examined the effectiveness of a modified McKenzie procedure in reducing spinal loading before circuit weight-training (CWT), and during recovery from exercise. The aim was to study the effects of pre- and post exercise mobilisation procedures, on physical responses to CWT, using spinal shrinkage as an index of spinal loading.

It was hypothesised that:

i) pre- and post-exercise mobilisation procedures attenuate or reverse the effects of spinal loading;

ii) a correlation is demonstrable between physical, physiological and behaviourial responses to CWT.

5. SURVEY OF INJURIES

5.1 INJURY PATTERNS AND TRAINING HABITS IN MARATHON RUNNERS

The potential for using epidemiological techniques to detect causes of injury in running were described in a previous section (Section 1.4.1.1). As yet only limited data are available on factors which may cause or put the runner at risk of injury. The results of three surveys to determine the prevalence of low-back pain and incidence of lower back injury among distance runners, and to link injury to associated training variables, are reported in this section.

In the first survey, entrants in the 1986 Mersey Marathon were used as subjects. A retrospective cohort questionnaire design, was used to determine the prevalence of low-back pain (this includes both existing and new injuries) and investigate extrinsic factors, which may influence injury risk among distance runners. The attitudes of the runners to training, injury and treatment were also examined.

In the second survey the same questionnaire was given to cross country runners from the Merseyside Colleges Cross Country League. This was to determine whether or not the training and injury profile of the marathon runner determined in the first study, differed from other distance runners.

In the third survey, a group of marathon runners from Merseyside athletics clubs filled in the same questionnaire to determine the prevalence of low-back pain. They then entered a longitudinal survey during which training diaries were kept to determine the incidence of injury.

5.1.1 RUNNING SURVEY 1: A RETROSPECTIVE SURVEY OF INJURY PATTERNS AND TRAINING HABITS IN RUNNERS IN THE MERSEY MARATHON

AIMS

The aims of this study were to develop a profile of the male marathon runner and his training habits; to determine the extent of the injury problem in the marathon running population; to determine the attitudes of runners towards injury prevention and treatment.

METHODS

Data were collected by means of a 34 item questionnaire (Appendix 1) which was posted to 1,923 runners who completed the 1986 Mersey Marathon. A stamped addressed envelope was enclosed.

The questionnaire consisted of 21 questions on training habits and 13 relating to injury status during the preceding 12 months. The questions were aimed at obtaining the following information:-

1) the quantity and quality of running in the 12 months prior to the marathon;
2) the length of time spent warming-up and warming-down before and after training and racing sessions;
3) the importance that the runners placed on warming-up and warming-down before and after training and racing;
4) the prevalence low-back pain in the previous 12 months;
5) the anatomical distribution of injury;
6) the runners approach towards gaining professional advice following injury;
7) the cause to which injury was attributed.

All correlation analysis was performed using Spearman's rank correlation coefficient, using MINITAB Statistical Software.

RESULTS

Altogether 338 replies from a population of 1,923 were receiveed. This represents an 18% return. As the questionnaires were distributed by the event organisers, access to non-respondents for the sake of comparison was not possible. On average the marathon runners were 36.4 (9.2) years of age, had 4.9 (4.2) years running experience and ran 38.8 (17.2) miles per week. The mean time for completion of the marathon was 3 hours 42 minutes (35 min). The sample was heterogeneous with ages ranging from 17-64 years, running experience from 0-33 years, weekly mileage from 0-120 milies and marathon time from 2 hours 26 min to 5 hours 49 min.

It was found that 90% of all training mileage was completed on the road and 84% of the total distance covered was run at a steady pace. Only 10% of training was performed on grass or synthetic surfaces and 16% at interval or fartlek pace (Table 5). (Fartlek is Swedish for speed play and refers to a method of training in which the runner adopts alternate fast and slow paces at will). Only 8% of runners had training schedules devised by qualified coaches.

The runners had 1.9 injuries each on average during the 12 month period. Injuries to the knee, lower leg and foot accounted for 67% of all injuries, the respective contributions being 25%, 29% and 13%. Lower back injuries accounted for 12% of all injuries, hip and pelvis for 8% and the hamstrings and thighs for 13%. Low-back pain was reported by 72 of the 338 runners, a prevalence of 21%. Of the 338 runners, 76% had been injured in the 12 months prior to the survey: 75% of these injuries occurred during training and 25% whilst racing (Table 6).

Table 5. Training characteristics of the marathon runner

n=338	Mean	SD	Range
Number of training days per week	4.6	1.5	0 - 7
Miles per week	38.8	17.2	0 - 120
Miles on road	35.1	16.9	0 - 120
Miles on grass	3.5	7.1	0 - 55
Miles on synthetic	0.3	1.6	0 - 20
Miles steady	32.6	15.9	0 - 120
Miles interval	2.3	4.9	0 - 35
Miles fartlek	4.1	7.1	0 - 54

Training error was reported to account for 56% of all injuries. Excessive mileage was the most commonly given cause of injury (28%). An abrupt change of mileage and a change of running surface were also commonly reported causes, 18% and 10% respectively. Inadequate footwear was the given cause of injury in 13% of cases. The remaining runners gave a variety of other reasons for their injury. In order to estimate the quality of footwear used, runners were asked how much they paid for their shoes (values being expressed in 1986 prices). Less than £10 was paid by 2% of runners, £10-£20 by 26%, £20-£30 by 30% and over £30 by 42%. Chi-square analysis for association between categorical variables revealed no relationship between shoe quality and injury.

Table 6. Anatomical site of injury to the marathon runner in the 12 months prior to the race.

n = 338	Training injuries	Racing injuries	Total
Lower back	53	19	72 (12%)
Hip/pelvis	37	14	51 (8%)
Thigh	29	13	42 (7%)
Hamstrings	30	10	40 (6%)
Knee	116	39	155 (25%)
Calf	44	8	52 (8%)
Shin	39	7	46 (7%)
Ankle	66	2	88 (14%)
Foot	58	2	80 (13%)
Total	427 (75%)	154 (25%)	626

Training was affected in 87% of all cases of injury. The runners were prevented from training in 61% of cases, and the quality of training was reduced in 23% of cases, while 3% of injuries required hospital treatment. Only 13% of injuries had a negligible effect on training. Once an injury had been sustained during training, 75% of runners continued to run. Subsequent to injury, 60% of runners attempted further training. The severity of injury was correlated with whether the runner continued to run immediately after onset, or continued to train once injury occurred ($r=0.675$ and $r=0.719$, respectively, $P<0.05$).

Only 16.5% of the injured sought professional advice within 24 hours, 16% within one week, and 26% over one week later and 44% sought no advice at all. When advice was sought the most common source was the local physician or general practitioner (32%). Only 17% of injured runners consulted a physiotherapist.

Warming-up routines were performed by 65% of runners before training and by 85% before a race. Warming-down exercises were only carried out by 40.2% of runners after training and 41.2% after racing. When asked how important they regarded their warm-up, less than half the runners (40%) indicated that it was "very important", and 21% "fairly important ". Warming-up was regarded as "unimportant" by 15% of runners. The warm-down was regarded less highly with nearly half of all the runners (49%) regarding it as "unimportant", 14% as "important" and 17% as "very important".

Attitudes towards warming-up were not reflective of the amount of time spent on this aspect of training. Only 5% of runners spent more than 15 min warming-up, 15% 10-15 minutes, 38% 5-10 min and 42% less than 5 min. A similar trend was observed with the warm-down but even less time was allocated to this aspect of training. Only 2% of runners spent more than 15 min warming-down, 7% between 10 and 15 min, 13% 5 to 10 minutes and 78% less than 5 min. There was a significant correlation between attitudes towards warm-up and warm-down and the amount of time allocated to these aspects of training, $r=0.527$ and $r=0.547$, $P<0.05$).

DISCUSSION

The relatively low response rate of 18% may be attributable to the length of the questionnaire, which required considerable time and motivation to complete. Personal approaches to the race entrants in order to ensure completion and return of the questionnaire were not permitted by the race organisers. Appreciably higher return rates are unlikely to be achieved without personal approaches to subjects. It is possible that the sample was skewed towards those who were or previously had been injured, as they would be the sub-section of the population with a vested interest in knowledge of running injuries. However, when the results of the survey are considered, fears of skew can be repudiated. Firstly, the data show that the sample is diverse in terms of age, experience and training characteristics; secondly, the injury profile of the sample (Table 6) is similar to that found by previous authors (Section 1.6); and thirdly, it has been the practice of some previous authors (Koplan et al., 1982) to conduct telephone interviews with a sample of non-respondents to elucidate whether or not their responses would differ from their compliant counterparts. Results of these studies indicate that no significant differences occur between respondents and non-respondents with respect to training habits or injury. In this study it was not possible to contact non-respondents as the posting of the questionnaires was handled by the race organisers. This meant no details of the names addresses and telephone numbers of non-respondents were available for follow-up.

The data collected identify a number of possible faults with the training regimens of marathon runners which may predispose to injury and therefore warrant further investigation. The majority of the weekly mileage, which in some cases exceeded 100 miles (160 km) per week, was performed on hard road surfaces at an even pace. Little use was made of alternative surfaces to the road, such as grass, forest paths or synthetic tracks. Alternative methods of training, to steady paced running, such as in interval and fartlek training, in which the speed of running is varied, were also largely ignored. Adoption of a more varied training regimen and environment may allow athletes to reduce stresses imposed on the lower body structures during training and perhaps reduce the incidence of injury.

Although the patterns of injuries in this study are similar to previously reported findings (Sheehan, 1977; Lutter, 1980; Temple, 1983; Maughan and Miller, 1983), the present data suggest an increase in the number of back related disorders. It is possible that the retrospective sampling techniques used in the present and previous studies, underestimated the prevalence of low-back pain in the running population, as runners prevented from competing in the race due to injury are excluded.

The clear majority of injuries (75%) occurred during training, supporting the findings of James et al. (1978), Reilly and Foreman (1983) and Maughan and Miller (1983). Lysholm and Wiklander (1987) showed that 72% of all injuries were caused by one or more training faults. This again compares favourably with present findings in which 56% of runners blamed a training error for their injury. A further detail which could indicate training error to be the major cause of injury was the extremely low number of runners who had their schedules devised by a coach (8%). A properly devised training schedule including the correct warm-up and warm-down procedures, utilising a variety of training environments and speeds may reduce the load on the body and hence on the spine.

Training variables can be deemed to be extrinsic factors with the potential to affect injury rates. Extrinsic factors could be manipulated in a controlled trial to determine which aspects of training reduce loading and perhaps protect against injury. This area is in need of urgent research consideration.

A further extrinsic factor examined was the quality of footwear used by the runners. Arbitrary quality boundaries were chosen on the basis of 1986 running shoe prices, with £30 delineating the boundary between a "good" quality shoe and a shoe of lesser quality. Most runners (58%) wore shoes of lesser quality with 2% wearing shoes costing less than £10. Even though these categories are arbitrary and choice of footwear is a matter of personal preference, these findings suggest that most runners could improve their quality of footwear, though it is not possible from the data to link shoe quality determined by cost to injury.

Once runners were injured they were slow to seek professional advice. Only 16.5% received treatment within 24 hours. Delay in obtaining treatment can lead to an acute mild injury becoming chronic and severe. The general practitioner was the main source of advice on injury. Lacking specialist knowledge on sports injuries, the General Practitioner may not be the best source of information or treatment. Only 17% of runners saw a physiotherapist for treatment. This underlines the need for more specialised sports injuries clinics which are readily accessible to the injured athletes.

Warming up and warming down may affect injury risk. Attitudes towards these aspects of training were examined. Although the majority of runners (65%) warm-up before training, the importance of the warm-up as an integral part of training was not regarded highly. Runners held a less favourable attitude towards warm-down, with only 40% of runners including the warm-down in their training regimen. Almost half of the runners regarded the warm-down as "unimportant". The actual time spent warm-up and warm-down was minimal, and therefore of doubtful benefit.

The overall picture that has emerged as a result of this survey is that a high proportion of runners do become injured. Many continue to train despite injury, thereby increasing the severity of their injury. Injured runners are generally slow to seek professional advice and treatment, though they may not have easy access to specialist help.

The low-back pain prevalence of 21% may represent a special problem to the runner. Cannon and James (1984) reported that the average time period spent visiting a sports injuries clinic by people with low-back pain was 41 weeks. This is substantially longer than for most other injuries. Low-back pain is a particularly debilitating disorder worthy of attention in the future.

Further investigation of the relationship between extrinsic factors such as footwear, running surfaces and training programme construction and low-back injury, may help in reducing the number of injuries. The manner in which these variables interact withh the runner's characteristics to affect injury requires scientific investigation.

5.1.2 RUNNING SURVEY 2: A RETROSPECTIVE SURVEY OF INJURY PATTERNS AND TRAINING HABITS AMONG CROSS-COUNTRY RUNNERS

A questionnaire (Appendix 1) was designed to determine whether marathon runners were the same as cross-country runners with respect to training regimens, injury profiles and attitudes towards the treatment of injury. A comparison of the relative risk of injury between the two groups, particularly with respect to low-back injury, may highlight possible aetiologies.

METHOD

Forty four cross-country runners were approached at the end of a Merseyside Colleges Cross-Country League race. The league was contested over eight mid-week races held throughout the cross-country season (October to March). It was open to teams of cross-country runners from business, public service and higher educational institutions in the Merseyside region. All the entrants who were approached completed and returned the questionnaire.

RESULTS

The average age of the cross-country runners was 27.7 (+8.7) years. The group had an average of 9.2 (+8.2)

Table 7 Anatomical distribution of injury in cross-country runners over 12 months. Comparison with marathon runners in parentheses (n=44)

	NUMBER OF INJURIES						
	Training		Racing		Total		
Lower back	13	17%	4	14%	17	16%	(12%)
Pelvis/hip	8	13%	3	11%	11	11%	(8%)
Thigh	2	3%	1	4%	3	3%	(7%)
Hamstring	5	9%	4	14%	9	9%	(6%)
Knee	14	18%	3	11%	17	16%	(25%)
Calf	6	8%	3	11%	9	9%	(8%)
Shin	10	12%	2	7%	12	11%	(7%)
Ankle	11	14%	5	9%	16	15%	(14%)
Foot	8	10%	2	7%	10	10%	(13%)
Total	77	(74%)	27	(26%)	104		

years running experience, ran 5.9 (±2.2) days per week, 42.1 (±21.7) miles per week and raced 1.7 (±0.8) times per month. Of the 44 cross-country runners questioned, 41 had been injured in the previous 12 months. Table 7 shows the comparison of anatomical distribution of injuries from the survey of cross-country runners. The data reveal that the runners sustained an average of 2.4 injuries each in the previous 12 months. The lower back was reported injured by 17 of the 44 runners, a prevalence of 39%. None of the injuries were related to any of the training variables examined.

The road was the most frequently used training surface, accounting for 77% of training mileage. Grass and synthetic surfaces were used for 18% and 5% of training mileage respectively. The pace of training mileage varied, the majority (72%) being run at a steady pace. Fartlek training was used for 15% of mileage and interval training 13%. Although 81% of the cross-country runners were athletic club members, only 37% had their traiining schedule devised by a coach.

On average the cross-country runners spent 14.5 (±9.6) min warming-up and 8.4 (±7.5) min warming-down. The warm-up was regarded as a "very important" aspect of training by 51% of the cross-country runners, 21% thought it "important", 17% "fairly important" and 10% "unimportant". The warm-down was performed after training by 57% of the cross-country runners and by 67% after racing. The warm-down was regarded as a "very important" aspect of training by only 24% of runners, 36% thought it "important", 16% "fairly important" and 24% "unimportant".

DISCUSSION

The cross-country runners were generally younger, more experienced and better trained than their marathon running counterparts. This is probably because many participants entering marathon events are recreational runners and not serious athletes.

The marathon runners questioned in the previous survey (Section 5.1) had a similar anatomical distribution of injury to the cross-country runners surveyed (Table 7). Differences were observed in the prevalence of back and leg injuries. The prevalence of low-back pain in marathon runners from the retrospective survey of running injuries to Mersey Marathon runners (Section 5.1) was 21% over 12 months (72 reported injuries among 338 runners). This compared with a prevalence of 39% for cross-country runners (17 reported injuries among 44 runners) over the same period. The incidences for the most commonly injured joint, the knee, were 39% in marathon runners and 45% in cross-country runners. The data suggest that the risk of lower back injury is less in marathon than cross-country running, whereas the risk of knee injury is increased. The higher rate of lower back injury in cross-country runners may be due to the greater use of uneven terrain used by the cross-country runners in training (18%) when compared with the recreational marathon runners (10%). Marathon runners tend to train on a more unyielding surface which could explain the high rate of knee pain. This does not explain the absence of a similar high rate of injury to the ankle joint.

Proportionally more cross-country than marathon runner, belonged to athletics clubs and had their training schedules devised by a qualified coach. This may account for the more positive attitudes towards warming-up and warming-down, and greater time spent on these activities, found among the cross-country runners. Although 81% of the cross-country runners were athletic club members, only 37% had their training schedule devised by a coach.

A pre-training warm-up was performed by 71% of the cross-country runners, and a pre-race warm-up by 93%. This difference is possibly because the slower pace of running in the initial stages of training was regarded as sufficient warm-up. The data show that warm-up and warm-down procedures were performed by a greater proportion of cross-country than Mersey Marathon runners. This was paralleled by the cross-country runners' more favourable attitudes toward this aspect of training.

Only 40% of marathon runners regarded the procedure as "very important" and 15% regarded it as "unimportant". Similarly, the warm-down procedure was performed by fewer marathon than cross-country runners, with only 40% of marathon runners warming-down after training and 41%

after racing. The marathon runners also regarded the warm-down as less important than the cross-country runners, 49% considering the procedure to be "unimportant" and 17% "very important". These characteristics probably reflect the shorter duration but higher intensity of exercise in cross-country compared to marathon running.

From the available data it is not possible to attribute causal links between the incidence of injury in cross-country runners and marathon runners and extrinsic training factors. The next section details an epidemiological survey of marathon runners. Prospective and retrospective surveys were used to ascertain the prevalence of low-back pain and incidence of lower back injury and determine the possible effects of extrinsic training variables on injury rate.

5.1.3 RUNNING SURVEY 3. A RETROSPECTIVE AND LONGITUDINAL SURVEY OF INJURY PATTERNS AND TRAINING HABITS IN COMPETITION MARATHON RUNNERS

INTRODUCTION

This extended the previous retrospective survey of Mersey Marathon runners, in which it was not possible to determine the incidence of lower back injury. The cohort of runners investigated in this survey were all actively involved in competitive distance running on road.

The survey was divided into two parts to determine both the prevalence of low-back pain and the incidence of lower back injury in a group of club marathon runners. Part 1, a retrospective survey of running injuries, entailed volunteer marathon runners filling in a questionnaire (Appendix 1). The results are given in Section 5.1.3.1. The survey was designed to determine the prevalence of low-back pain in the sample of runners. Part 2, a longitudinal survey of running injuries, involved the same group of runners filling in a diary of training habits and injury occurrence (Section 5.1.3.2). The aims of the diary were twofold: to allow determination of the incidence of lower back injury; and to determine whether or not the incidence of injury was related to extrinsic training variables.

The main extrinsic variable under investigation were: the mean number of runs per week; the mean total weekly milage; the mean number of miles per run; the mean time taken for each run; the mean speed of running; the mean distance of each run; the mean percentage of time spent running at a steady pace; the mean percentage of time spent running on the road; the mean number of hours spent running each week; or the mean number of days spent running each week.

5.1.3.1 PART 1. RETROSPECTIVE SURVEY OF CLUB MARATHON RUNNERS

METHOD

Three running coaches of three Merseyside athletics clubs, were contacted and requested to recruit volunteer marathon runners to the study. A group of 64 marathon runners volunteered to take part in the survey. It is not known how many distance runners were in each club so the size of the sample as a proportion of the club population cannot be determined. However, it is unlikely that 3 coaches would be in charge of more than 64 runners, so it is probable that the sample is representative of club runners. The coaches distributed the questionnaire (Appendix 1) and a training diary to each volunteer. The retrospective questionnaire (for further details see section 5.1.) was designed to provide information on training habits and injury status of the runners during the preceding 12 months. The runners were asked to complete the questionnaire and return it in a provided stamped addressed envelope. All the runners returned the questionnaire.

RESULTS

The average age of the 64 runners was 34.7 (±8.5) years. The group had an average of 7.1 (±5.3) years running experience, ran on 5.8 (±1.0) days per week, an average of 48.3 (±17.0) miles per week and raced 1.5 (±0.8) times per month.

The road was by far the most frequently used training surface, accounting for 81% of the training mileage. Grass and synthetic surfaces were used for only 16% and 3% of training mileage, respectively. The pace of training varied, the majority (74%) of training mileage being run at a steady rate. Fartlek training was used for 12% of mileage and interval (intermittent) training accounted for a further 14%.

Even though all of the runners were athletic club members, only 34% had their training schedule devised by a coach. Pre-training warm-up was performed by 67% of the runners and by 97% prior to racing. While 45% of the runners regarded the warm-up as a "very important" aspect of training, 23% thought it "important", 28% "fairly important" and 4% "unimportant".

Warm-down was performed post-training by 64% of the runners and by 67% after racing. The warm-down was regarded as a "very important" aspect of training by 28% of the runners, 22% thought it "important", 33% "fairly important" and 17% "unimportant". On average the runners spent 11.7 ($\pm$6.9) min warming-up and 7.3 ($\pm$6.9) min warming-down.

Of the 64 runners questioned, 60 had been injured in the previous 12 months. One hundred and forty three injuries were reported. That is 2.2 injuries per runner per annum. Table 8 shows the anatomical distribution of injury among the runners. Seventeen of the runners reported lower back injury in the preceding 12 months. This represents an prevalence of 27%. Fourteen runners named some activity which exacerbated the pain, five citing running as such an activity. However, postures to relieve the pain could be adopted by 11 of the runners.

Immediately following injury, 74% of runners continued with their run. On subsequent days 55% continued to train when injured. Training was prevented by 79% of injuries, the quality of training reduced in 19% of cases and only 2% of injuries had negligible effect. In cases where the injury occurrence was sudden, 70% of injuries occurred on the road, only 16% and 2% on grass and synthetic surfaces and 12% gave some other surface as source.

Table 8. Anatomical distribution of injury in club marathon runners (12 months retrospective) (n=64)

NUMBER OF INJURIES						
Site of injury	Training		Racing		Total	
Lower back	14	14%	3	7%	17	12%
Pelvis	1	1%	0	0%	1	0%
Hip	7	7%	4	9%	11	8%
Thigh	5	5%	3	7%	8	6%
Hamstring	12	12%	6	13%	18	13%
Knee	17	18%	7	15%	24	17%
Calf	8	8%	7	15%	15	10%
Shin	6	6%	2	4%	8	6%
Ankle	14	14%	5	11%	19	13%
Foot	13	13%	9	20%	22	15%
Total	97	68%	46	32%	143	

An excessive mileage was blamed for 24% of injuries, a change of running surface for 18%, inadequate footwear for 14%, an abrupt change of mileage for 10% and 34%

injury to attributed to other causes. The majority of runners spent more than £30 on running shoes (60%), 34% spent between £20-£30 and 6% between £10-£20.

No advice on injury was sought by 9 of the 41 runners who had been injured. Of those seeking guidance the main source of advice regarding treatment was from the General Practitioner (38%), followed by the physiotherapist (25%) and the athletes coach (8%). Hospital attention was required in 18% of cases and alternative sources of advice or treatment were sought in 6% of the injured. Twenty nine of the runners saw more than one source for advice. In the cases when advice was sought half the runners (50%) waited for more than one week before seeking help, 19% sought advice on the day they were injured and 46% within one week of injury.

DISCUSSION

In contrast to the runners in the Mersey Marathon (Section 5.1.1), who were a heterogenous sample of runners with a wide range of running abilities, the runners in this survey were all actively training members of running clubs. The runners in the Mersey Marathon and the club runners in this survey were of a similar age 36.4 (±9.2) years and 34.7 (±9.5) and respectively. The club runners had on average over 2.2 more years running experience than the Mersey Marathon runners, 4.9 (±4.2) and 7.1 (±5.3) years respectively. The club runners also had a weekly mileage 25% higher than the Mersey Marathon runners (48.3 (±17.0) and 38.8 (±17.2) miles respectively). These differences are probably due to the recreational runners in the Mersey Marathon population who were less highly trained than the club runners. However, some of the runners in the marathon were highly trained and so the differences are less pronounced than would otherwise be expected.

The quality of training was more varied among the club runners, who spent a smaller proportion of their training time running on the road than the recreational Mersey Marathon runners (81% and 90% respectively) and less time running at a steady rate (74% and 84% respectively).

Table 9. The proportion of club marathon runners (n=64) and runners in the 1986 Mersey Marathon (n=338) who warm-up and warm-down.

	Club Runners		Mersey Marathon Runners	
	Training	Racing	Training	Racing
Proportion of runners who:				
Warm-up before running	67%	64%	65%	40%
Warm-down after running	97%	67%	85%	41%

Table 9 shows that the club runners were more likely than the marathon runners to warm-up and warm-down before running. It was also found that attitudes of the club runners were more positive than the Mersey Marathon runners, towards warming-up and warming-down were more positive (Table 10). A greater proportion of the club runners regarded these aspects of training more highly. This was particular true for the warm-down after racing which was regarded as "very important" by 17% of the Mersey Marathon runners and 28% of the club runners and "unimportant" by 49% of the Mersey Marathon runners and 17% of club runners.

Table 10. Attitudes of club (n=64) and Mersey Marathon runners (338) towards warming-up and warming-down

	Club Runners		Mersey Marathon Runners	
Runners opinion of:	Warm-up	Warm-down	Warm-up	Warm-down
"very important"	45%	28%	40%	17%
"important"	23%	22%	24%	33%
"fairly important"	28%	33%	21%	20%
"unimportant"	4%	17%	15%	49%

The anatomical distribution of injury (Table 8) was similar to that of the Mersey Marathon runners. Both surveys revealed that 12% of running injuries were to the lower back. In this survey 17 of the 64 runners reported low-back pain in the preceding 12 months, a prevalence rate of 27%. Of these 11 stated that some postures could alleviate low-back pain symptoms. This knowledge has been used in Section 7 to determine whether warm-up and warm-down activities could be manipulated to reduce or reverse spinal loading caused by running in asymptomatic runners. If this were so, such exercise could potentially reduce the incidence of lower back injury among runners.

5.1.3.2 PART 2: A LONGITUDINAL SURVEY OF COMPETITION MARATHON RUNNERS

METHODS

Forty four of the 64 marathon runners who completed the retrospective questionnaire (described in section 5.1.3.1) agreed to keep a training diary for 40 weeks. The runners were asked to record any injury occurring over the 40 week duration of the study, and their training schedule. This would provide information on the extrinsic variables which may predispose towards injury. Instructions on how to enter information in the diary were given on a sample page, the first page of the diary (Appendix 3). Details of the distance of each run, the time taken for each run, and the type of training undertaken were requested. Any injury arising was documented and the runner was asked to state whether or not training was affected. To aid memory recall, the runners were instructed to fill in the diary as soon as possible after each run.

RESULTS

Of the 44 runners originally given a diary for the 40 week period, nine were excluded from the analysis because they had logged the data incorrectly, were injured other than through running or failed to return the diary. Thirty five runners completed the diary satisfactorily.

In the 40 week period during which a running diary was kept, the subjects ran 5.4 (±1.94) times per week, an average of 37.02 (±14.90) miles per week. The mean length of each run was 6.7 (±1.3) miles or 10.7 (±2.9) km at a speed of 6.5 (±0.5) $mile.min^{-1}$ or 10.5 (±0.8) $km.h^{-1}$.

Road running accounted for 74% of the training mileage, whilst 84% of the mileage was run at a continuous rate. The average training mileage of 6.7 per run was performed in a mean time of 42.8 (1.36) min. On average 3.9 hours were spent each week in training. The runners averaged 1.9 rest days per week.

The 35 runners reported 128 injuries, an average of 3.7

(1.9) injuries per runner over the 40 week period. The anatomical distribution of injuries is listed in Table 11. The results of the longitudinal survey showed that 13 of the 35 runners suffered from lower back injury during the 10 months period. The incidence of lower back injury was 37%.

Table 11. Anatomical distribution of injuries in club marathon runners (Longitudinal) (n=35).

Site of injury	Number of injuries	Percentage of total
Lower back	13	10
Pelvis	0	0
Hip	14	11
Thigh	9	7
Hamstrings	14	11
Knees	16	12
Calf	14	11
Shin	8	6
Ankle	20	16
Foot	20	16
Total	128	

Spearman's Rank Correlation analysis revealed that the total number of injuries sustained by the runners was unrelated to the extrinsic training variables ($p>0.05$). A Chi-squared test for association of categorical variables was performed on the data to determine whether the occurrence of lower back injury in runners was associated with any of the extrinsic variables outlined in Section 5.1.3. The mean values for these extrinsic variables were determined and the runner's category placed into a 2 x 2 contingency table for each extrinsic variable.

The presence or absence of lower back injury was not associated with either an above average or below average score in any of the extrinsic variables ($p>0.05$). The method of categorising the runners by dividing them above and below the mean for each extrinsic variable, may lead to insensitivity in the mid-range. This could have been overcome by removing the middle range values from the analysis. However, the low number of subjects ($n=35$), only 13 of whom were in the lower back injury category, did not permit this analysis.

In an effort to determine whether the 10 runners with lower back injury preceded injury by an increase in the training volume, the eight weeks preceding injury was divided into two 4-week periods. The 4-week period immediately preceding lower back injury was compared with the prior 4 weeks. Although the mileage in this period did increase from 142.5 ($\pm$70.4) to 154.0 ($\pm$53.9), a t-test showed that this difference was not significant.

DISCUSSION

The absence of a relation between the number of injuries sustained and mileage is in contrast to the findings of previous authors in cross-sectional studies (Pollock et al., 1977; Koplan et al., 1982; Reilly and Foreman, 1984; Blair., 1985; Powell et al., 1986). This study involved smaller numbers of subjects (n=35) than previous studies and adopted a longitudinal approach which prevented the bimodal analysis. In larger studies it is possible to exclude centrally distributed data from analysis and compare data from the extremes of a distribution. Also variability in training due to intermittent injury would mask a relation between training volume and injury in longitudinal studies. These factors may explain the discrepancy between current and previous findings.

The Chi-squared analysis indicated that in the present sample runners, those with lower back injury symptoms could not be separated from those without lower back injury on the basis of their training regimen. Therefore the extrinsic variables examined in this study were not shown to be the cause of lower back injury in the runners. It was also shown that an abrupt change in mileage did not precede lower back injury and could not be an aetiological factor.

5.1.3.3 SUMMARY OF OBSERVATIONS FROM THE RUNNING SURVEYS

In Sections 5.1.1 to 5.1.3.2 the training and injury patterns in three groups of runners were examined, including runners in the Mersey Marathon, cross-country league runners, and athletics competition marathon runners. The aims of the surveys were to: determine the prevalence of low-back pain among recreational marathon runners; determine whether distance runners other than recreational marathon runners had the same injury profile as marathon runners; determine the incidence of lower back injury in marathon runners; determine whether extrinsic training variables were associated with occurrence of injury.

The anatomical distribution of injuries in the thee groups of runners surveyed (Table 12) were similar in the three studies. The percentage of injuries to the lower back ranged from 10-16%, the cross-country runners having the highest proportion.

The anatomical distribution of injuries in the surveys show a higher proportion of injuries to the lower back than observed by previous authors (Sheehan, 1977; Lutter; 1980; Maughan and Miller, 1983; and Devereaux and Lachmann, 1983; Temple et al., 1987). On average the proportion of injuries to the back in these studies was

6%, compared with an average of 12.5% in the present surveys. These differences are more likely to reflect differences in sampling technique and survey design, rather than an increase in the proportion of back injuries (Powell et al. 1986).

Table 12. Summary of the anatomical distribution of injury in runners from the three surveys.

	Survey 1. Mersey Marathon Runners (n=338)	Survey 2. Cross Country Runners (n=44)	Survey 3. Competition Runners Retrospective (n=64)	Survey 3. Competition Runners Longitudinal (n=35)
	Distribution of injuries (%)			
Site of injury:				
Lower back	12 (21%)	16 (39%)	12 (27%)	10 (37%)
Pelvis/Hip	8	11	8	11
Thigh	7	3	6	7
Hamstring	6	9	13	11
Knee	25	16	17	12
Calf	8	9	10	11
Shin	7	11	6	6
Ankle	14	15	13	16
Foot	13	10	15	16

(Prevelance rates and Incidence rates in brackets)

The retrospective surveys revealed, the prevalence of low-back pain the three cohorts to be 21%, 27% and 39% over a 12 month period, in the Mersey Marathon runners, the competition marathon runners and the country runners respectively. This might suggest an abnormally high incidence of low-back pain among cross-country runners. These findings support those of Brunet et al. (1990) who found a prevalence rate of 35% for low-back pain in U.S. distance runners, which is close to the 39% for cross-county runners in this study.

The longitudinal survey of club marathon runners revealed an incidence rate for lower back pain of 37%. This might seem high when compared with the prevalence rates of between 21% and 39% from the retrospective surveys. Exclusion of the runners not participating due to injury would lead to a slight inflation of the figures. Injured runners, unable to compete at the time of the surveys, were not in the sample and therefore not included in the calculation for prevalence. Therefore the prevalence of low-back pain may have been underestimated. In the longitudinal survey all injuries were documented, even those which prevented training and competition. However, there was a 58% drop out between the studies which may have reduced the injury rate.

In the three retrospective surveys the majority of injuries occurred during training. Among the Mersey

Marathon runners 75% injuries occurred in training, the figure being 74% in the cross-country runners and 68% in the club marathon runners. This confirms the findings of James et al. (1978), Reilly and Foreman (1983) and Maughan and Miller (1983).

Analysis of the training regimens in the three retrospective studies showed that the majority of all training occurred on the road and at a steady state. Little use was made of alternative running surfaces or paces of running. The cross-country runners and club marathon runners used more diverse training programmes than the Mersey Marathon runners,spending 74% and 77% of the training running on the road and 72% and 84% at a steady pace. The Mersey Marathon runners spent 91% and 84% of their training mileage running on the road and at a steady state, respectively.

The proportion of mileage run on the road and at a steady pace does not give the absolute mileage performed and can therefore be misleading. When the proportion of mileage spent running on the road, is multiplied by the actual weekly mileage for each group, to give the actual mileage covered, the followinng trend emerged. Club marathon runners ran on average 36.0 miles on the road, Mersey Marathon runners 35 miles and cross-country runners 32.0 miles. The same trend emerged for the weekly mileage at a steady running pace. Club Marathon runners ran an average of 40 miles at a steady pace, Mersey Marathon runners 33 miles and cross-country runners 30 miles. Although the club runners had a more varied training programme than the Mersey Marathon runners, a greater absolute mileage was performed on the road and at a steady pace.

Analysis of the data in the longitudinal survey of club marathon runners failed to show a relationship between extrinsic training variables and injury. Neither were there any correlations between injury and training variables in any of the retrospective surveys. Previous research has identified a link between training mileage and injury risk (Pollock et al., 1977; Koplan et al., 1982; Reilly and Foreman, 1984; Blair., 1985; Powell et al., 1986). Apart from this discrepancy this survey supports the findings of previous work (Koplan et al., 1982; Blair et al., 1987; Powell et al., 1986).

This study did not explore intrinsic factors such as physiological, anthropometric or biomechanical variables, which in association with inappropriate training techniques could cause lower-back injury. Future research should be experimental in design and concentrate on the role of anthropometric and biomechanical variables for example, anatomical inequalities in leg length (Brunet et al. 1990), which may predispose to low-back pain. In parallel with this runners of differing abilities should follow pre-determined training regimens in which the extrinsic variables outlined in Section 5.1.2 are manipulated. Differences in the incidence of lower back injury in controlled regimens could then be determined and possible aetiological factors identified.

The role of the warm-up and warm-down in training regimens was examined in the three retrospective surveys. In all cases the athletes regarded the warm-up more highly than the warm-down and a greater amount of time was spent on warming-up than warming down. Cross-country runners and club marathon runners had a more positive attitude towards warming-up and warming-down than the Mersey Marathon group. This was evident in the greater amount of time spent on these activities in the two groups, when compared to the Mersey Marathon cohort. This level of analysis is not sufficient to allow inferences to be made as to the efficacy of such procedures in injury prevention. The role of warm-up and warm-down procedures should be investigated experimentally to determine their effect on injury rates. Some runners who reported low-back pain in the 12 months prior to survey also stated that running exacerbated the pain. They also reported that postures could be adopted to alleviate pain when not running. It is possible that warm-up and warm-down procedures could be modified and used to reduce spinal loading caused by running. If it could be demonstrated that spinal loading caused by running was attenuated or reversed, the procedures could be included in warm-up and warm-down regimens to reduce spinal loading. The effects of these procedures could be determined by measuring spinal shrinkage. This has yet to be determined and is investigated in Section 7. Spinal shrinkage induced by running may be different in runners with and without low-back pain. This has not been established and will be examined in Section 6. Previous research into spinal loading and distance running has not examined the effect of a run of the length and duration of the marathon on spinal shrinkage. This will also be examined in section 6.

5.2 WEIGHT-TRAINING SURVEY: A SURVEY OF INJURIES AND ATTITUDES TOWARDS TRAINING IN WEIGHT-TRAINERS

The aim of this survey was to determine the prevalence of injuries in weight-trainers from weight-training gymnasiums by using retrospective questionnaires. Attitudes towards training and treatment of injury were also examined.

METHOD

A 33 item questionnaire was designed to provide information on the training habits, injuries and attitudes of weight-trainers (Appendix 2). Recruitment of subjects for this part of the study proved to be problematic although 30 weight-trainers participated in the survey.

RESULTS

The survey revealed the average ages of the 30 weight-trainers to be 32.0 ($\pm$10.8) years. The average training experience was 6.2 ($\pm$2.7) years, training 2.4 ($\pm$3.9) days per week, for an average of 64.2 ($\pm$37.1) minutes. When asked why they started weight-training 13 of the weight-trainers said "to improve general fitness", 12 "to lose weight", 4 "to gain weight" and 1 "to gain strength".

Table 13. Anatomical distribution of injuries in weight-training (n=30) in the previous 12 months.

Site of injury	Number of injuries
Neck	3
Shoulder	6
Upper Arm	0
Elbow	0
Forearm	1
Wrist	0
Hand	0
Chest	0
Ribs	1
Abdominal	0
Upper back	1
Lower back pain	4
Pelvis	0
Hip	1
Groin	2
Thigh	0
Hamstring	0
Knee	2
Calf	1
Shin	1
Ankle	0
Foot	1
Total	24

Table 13 shows the anatomical distribution of injuries in weight-training. A total of 24 injuries was reported by the 30 weight-trainers in the 12 months prior to survey. This is equivalent to 0.8 injuries per individual. Five of the injuries occurred in one subject.

Training schedules were devised by a supervisor of the gymnasium for 73% of the subjects, although it is not known whether the supervisors had formal qualifications. Pre-training warm-up was performed by 80% of the weight-trainers. While 59% of the subjects regarded the warm-up as a "very important" aspect of training, 17% thought it "important", 17% "fairly important" and 7% "unimportant". Warm-down was performed post-training by 52% of the subjects. The warm-down was regarded as a "very important" aspect of training by 21% of subjects, 21% thought it "important", 31% "fairly important" and 28% "unimportant". On average the weight-trainers spent 6.4 ($\pm$6.1) min warming-up. This compared with a mean value of 2.5 ($\pm$3.4) min warming-down.

Only 8 of the trainers reported an injury as being severe. Three of these were to the shoulder joint, the others to the calf, ankle, neck, groin and ribs. None of the back injuries was classified by the weight-trainers as their most severe injury. Training was prevented in only one case of injury; quality of training was reduced in seven cases, three had negligible effect, and the remaining 11 had no effect on training. Of the eight subjects who sought advice about injury one saw his coach, two saw a physiotherapist, three their general practitioner, one went to a hospital casualty department and one a fellow weight-trainer who was a doctor. Two of the injured sought advice immediately, one the day after injury, one less than a week after injury, and four more than one week later.

Four of the thirty subjects experienced chronic low-back pain, a prevalence of 13%. The mean duration of low-back pain since the first experience was 3.62 (±4.39) years. Four other trainers had low-back pain symptoms which were unrelated to weight-training. The most severe episode of low-back pain was rated 8 'very severe pain' on the pain rating scale (Appendix 2). The mean rating for the first episode was 6 (±1.6), "fairly severe pain" on the rating scale. The mean rating for the most recent episode was 4.5 (±0.9), between "fairly mild" and "medium" pain on the scale. Only one of the weight-trainers reported a sudden onset of low-back pain, this occurred whilst lifting. All the sufferers reported getting symptoms "a few times a year". No data were reported on the diurnal tends in severity of pain. Two of the sufferers reported lifting as an activity that exacerbated pain, and two reported bending. Low-back pain symptoms prevented sporting activity in one trainer, restricted activity in two others and had no effect on the third. One of the sufferers reported that pain could be relieved by sauna bathing or lying on a board, the other three did not report alleviating postures. None of the suffers were on medication or had surgery for the symptoms.

DISCUSSION

The management staff of some commercial weight-training facilities were approached to gain access to weight-trainers. Most were unwilling to allow surveys of injuries sustained on their premises. Two gymnasia supervisors allowed recruitment of their clients onto the study, but on the proviso that questionnaires would be distributed by employees of the gymnasia. This prevented personal interaction between the experimenter and the subjects which may explain the low return rate. Also, the population size from which the sample was drawn was unknown.

The subjects in this survey were experienced weight-trainers, having trained for an average of over 6 years. The type of training undertaken is unlikely to have been aerobic in nature. The mean length of a training session was over 1 hour and training was performed 2.5 times per week on average. This level of training is outside the ACSM guidelines (Section 6.4) for aerobic training. It is more likely that most of the subjects were interested in muscular rather than training for aerobic development.

Weight-training, unlike running involves a wide range of muscle groups and involves diverse movements. This accounts for the range of reported injuries. The prevalence of low-back pain (13%) in this survey was lower than that found in runners (21-39%). The proportion of the weight-training population from which this sample was drawn was not known so the prevalence of symptoms reported here is likely to be an underestimation. Due to lack of co-operation from the supervisors of the gymnasia the distribution of questionnaires was difficult to control and consequently the number recorded was low. Therefore the results must be treated with caution.

Clearly a different approach to collecting epidemiological data on weight-training injuries is needed. Municipal leisure facilities provide an alternative target population. These centres tend to cater for a broad spectrum of users more likely to be involved in weight-training, conditioning and circuit weight-training (Basford, 1985; Section 1.7). Commercial gymnasia tend to cater for bodybuilders and power-lifters who do not place emphasis on aerobic training to any significant degree. The prevalence of low-back pain in weight-trainers was found to be 13%, but the prevalence in circuit weight-trainers in particular remains to be determined. The incidence of injury in circuit weight-traininers also remains to be determined by longitudinal study, which could involve an analysis of injury rates under experimentally controlled conditions. It would be useful for the ergonomist to analyse the biomechanical load on the lumbar spine in different exercises used in circuit weight-training. The load handled by subjects and the postures involved in training could be evaluated by questionnaire and kinematic analysis. This could be related to the shrinkage induced and the perceptual responses of discomfort and pain. The cumulative loading over a 12 month time period could then be related to the incidence of injury.

The load on the spine caused by CWT needs to be investigated using spinal shrinkage, as does the role of pre- and post-exercise warm-up and warm-down activities in attenuating or reversing spinal loading. These problems are addressed in Sections 6.4 and 7.2.

6 EXPERIMENTAL SECTION

6.1 EXPERIMENT 1: RUNNING SPEED AND SPINAL SHRINKAGE IN RUNNERS WITH AND WITHOUT LOW-BACK PAIN.

INTRODUCTION

The aims of this present study were:- 1) to investigate the effect of running speed on spinal shrinkage; 2) to compare changes in stature caused by running in athletic subjects with and without low-back pain symptoms; 3) to determine the effects of age on spinal shrinkage in running. It was hypothesised that:- 1) an increase in running speed increases the amount of shrinkage incurred in a run of fixed duration; 2) spinal shrinkage is increased in runners with a history of low-back pain symptoms; 3) spinal shrinkage is reduced in older runners.

METHODS

Male marathon runners (n=14) were recruited as a result of a questionnaire survey carried out on participants in the 1986 Mersey marathon. The mean (SD) height, body mass and age for the group were 176.7 (±6.6) cm, 69.07 (±8.59) kg and 31 (±9) years, respectively. Seven of the runners had a history of, and still suffered from chronic low-back pain at the time of this study. The remaining seven were asymptomatic. Chronic low-back pain was defined as a pain between mid-back and buttocks occurring more than once a month, the first episode being at least 12 months prior to filling in the questionnaire. All subjects were healthy and gave written informed consent.

The marathon times for the symptomatic and asymptomatic groups were 3.57 (±1.35) and 2.96 (±0.72) hours respectively. Their half marathon times were 1.42 (±0.32) and 1.26 (±0.20) hours. These differences were non-significant ($P>0.05$).

This study examined the effect of three running speeds on two groups of runners, one group with chronic low-back pain. The two groups of seven male marathon runners, ran at 70%, 85% and 100% of their marathon race pace for 30 min on separate occasions. Before and after exercise the subjects were seated for 20 min with the lumbar spine supported. Stature was measured before pre-exercise sitting, before running, after 15 min running, after 30 min running and after post-exercise sitting.

Changes in stature were measured using a modified stadiometer described by Boocock et al. (1986). Each runner was required to undergo training on a stadiometer to ensure reliability of subsequent experimental measurements. On average, 2.4 (±1.0) training sessions were required, lasting 44.4 (±27.5) min in total, during which 44.3 (±23.6) measures of stature were taken, each over 5 s. A standard deviation of less than 0.5 mm over 10 consecutive measures was used as a criterion that the subject was adequately trained. All subjects achieved the target, the average deviation being 0.42 (range 0.26 -0.49) mm.

The experimental protocol consisted of a 20 min pre-exercise control period sitting relaxed in a chair with a lumbar support (Plate 2). This was followed by two consecutive 15 min runs on a motor driven treadmill. The second run was followed by a 20 min seated recovery period, with the back supported. Measurements of stature were made on five occasions:- prior to the control period; at the end of the control period (i.e. prior to the first 15 min run); after the first 15 min run; after the second 15 min run (i.e. within 30 s of the start of the recovery period); and after the recovery period. The mean of five consecutive, discrete measures was taken, between which the subject moved away from the stadiometer (Boocock et al., 1986). Measurement took 4.4 (±0.8) min which included time to allow heel compression to stabilize (Foreman, 1989).

Subjects performed the protocol on three separate occasions. At each session the running speed was altered. Subjects were randomly assigned to either 70%, 85%, or 100% of their individual marathon performance

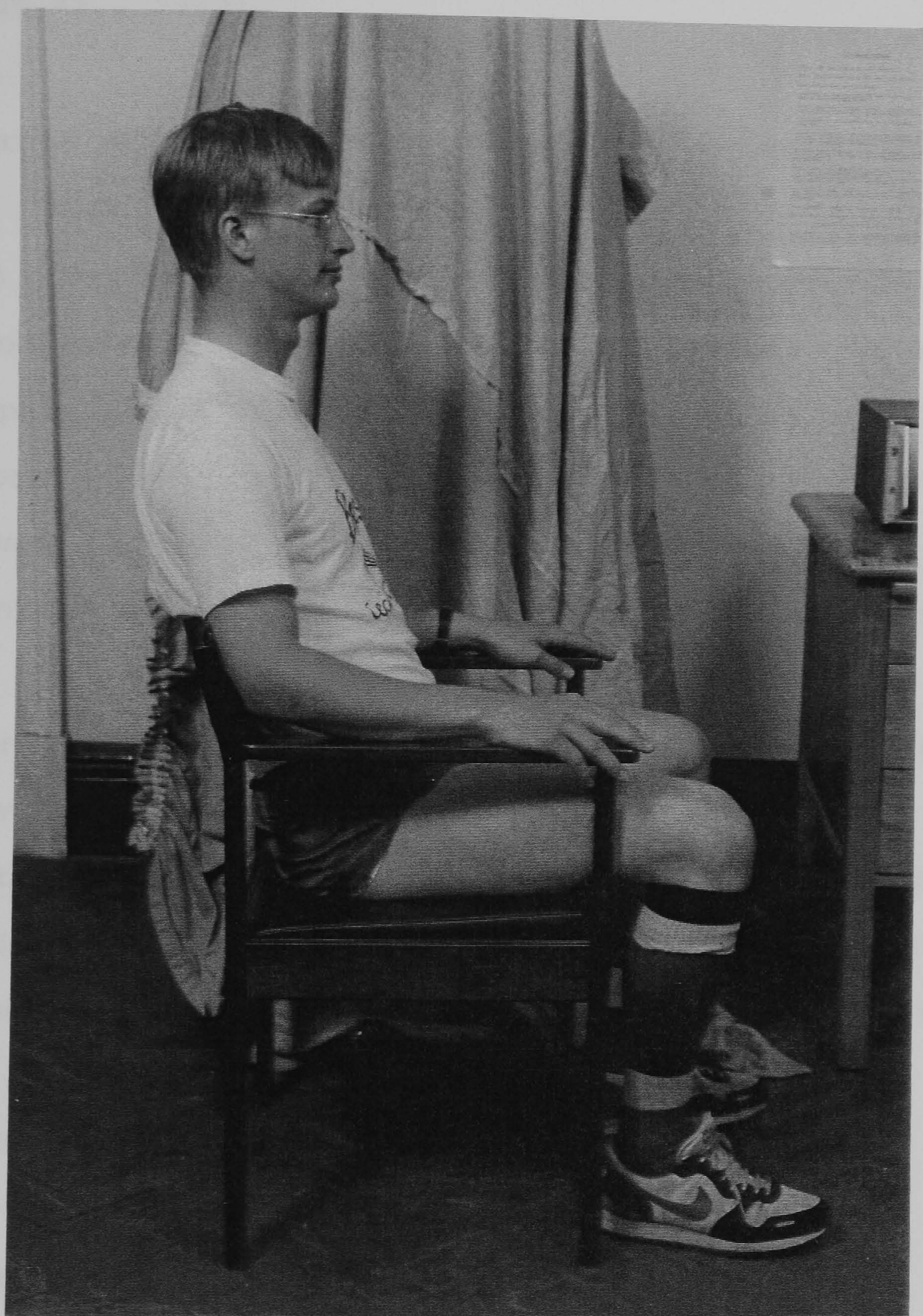


Plate 2. Subject sitting in a chair with a lumbar support.

speeds. Each visit was at 09:00 hours to control for circadian variation in stature (Tyrrell et al., 1985; Wilby et al., 1987).

Heart rate was measured throughout the protocol using a short range radio telemetry device (SPORT-TESTER, PE3000). Subjective ratings of perceived exertion (RPE) were monitored using Borg's (1972) RPE scale. An eleven point pain scale with '0' representing no pain and '10' the worst pain imaginable, was used as a rating of perceived low-back pain. In each case recordings were made in the last minute of the experimental conditions.

Heart rate responses to the test protocol and ratings of perceived exertion, were analysed by means of a non-parametric sign test to determine the comparative physiological and perceptual responses of the two groups. A probability level of P=0.05 determined significance.

RESULTS

No significant differences between the groups were found for heart rate (Table 14) either during the pre-exercise control period, the two consecutive 15 min periods of running or the recovery period. No difference was found in perceived exertion (Table 15) between the two groups in response to the two 15 min running periods. This indicates that running speeds selected caused equal physiological stress in the two groups, and that the groups were of a similar level of fitness.

The control group was verified as asymptomatic as all subjects in this group reported low-back pain ratings of zero throughout the experiment. This is in contrast to the pain ratings reported by the experimental group.

Table 14. Mean (SD) heart rate for runners with (Back) and without low-back pain (Non Back) n=14

	Heart rate (beats.min^{-1})							
	Rest		15min		30min		Recovery	
	Back	Non-Back	Back	Non-Back	Back	Non-back	Back	Non-back
100%	67	59	153	165	157	171	72	77
Race Pace	(12)	(14)	(14)	(18)	(13)	(21)	(13)	(13)
85%	67	61	140	149	141	151	73	75
Race Pace	(15)	(15)	(8)	(20)	(9)	(20)	(15)	(11)
70%	67	63	126	132	128	134	74	74
Race Pace	(13)	(10)	(15)	(18)	(15)	(20)	(15)	(12)

(*P<0.05)

The increases in the perception of pain between the 70%,

Table 15. Mean (SD) rating of perceived exertion for runners with (Back) and without low-back pain (non or non-back) n=14

	Rating of perceived exertion	
	After 15 min	After 30 min
100% pace		
Back	12.1 (1.1)	13.3 (1.8)
Non-back	13.1 (2.6)	13.6 (2.9)
85% pace		
Back	9.6 (1.7)	9.7 (2.1)
Non-back	11.9 (2.4)	11.9 (2.3)
70% pace		
Back	8.0 (1.7)	8.1 (1.9)
Non-back	8.9 (1.7)	9.4 (1.8)

(*P<0.05)

85% and 100% conditions did not reach significance (P>0.05). Nor did the pain differ between the first and second 15 min runs. A trend toward an increase in perception of low-back pain with an increase in exercise intensity and duration is illustrated in Table 17. The number of individuals registering pain at each stage and each intensity is given in Table 18. The ratings for the

70%, 85% and 100% conditions did not increase significantly with an increase in pace. Nor was the increase in rating between the first and second 15 min runs significant (p>0.05).

Table 16. Changes in stature during a 30 min treadmill run in runners with and without low-back pain.

		Low-Back Pain	Non Low-Back Pain
	Time (min)	Shrinkage (mm SD)	Shrinkage (mm SD)
Sitting	20	-1.1 (3.2)	-0.1 (2.6)
70% pace	15	3.6 (3.1)	0.8 (2.1)*
	30	1.3 (1.4)	1.1 (1.2)*
Sitting	20	-2.6 (1.3)	-0.2 (2.9)
Sitting	20	-1.6 (1.0)	-1.2 (2.1)
85% pace	15	3.2 (0.8)	2.8 (3.3) *
	30	1.5 (1.4)	2.7 (2.0)*
Sitting	20	-3.1 (1.8)	-3.1 (2.5)
Sitting	20	-2.9 (1.3)	-2.2 (1.6)
100% pace	15	4.3 (2.5)	5.0 (3.0)*
	30	2.9 (1.3)	3.1 (1.3)*
Sitting	20	-2.4 (1.3)	-2.3 (2.9)

(*P<0.01)

The effect of low-back pain symptoms and running speed on spinal shrinkage was analysed by two-way ANOVA. Results showed that spinal shrinkage throughout the experimental protocol was unaffected by the presence of back pain symptoms. No difference in spinal shrinkage (Table 16) observed between the speed conditions during the control period, after the first 15 min of running, or after the post-exercise recovery period. An effect of running speed was observed in the second 15 min run ($P<0.01$), and when shrinkage during the first 15 and second 15 min runs are summed ($P<0.005$). Table 16 shows a trend shows less shrinkage for a given load in runners without low-back pain symptoms: however, ANOVA revealed these differences to be non-significant ($P>0.05$).

Table 17. Back pain ratings (SD) for the symptomatic subjects under conditions of increasing running speed and duration.

	Percentage of marathon running speed		
	70%	85%	100%
After 15 min running	0.57 (1.51)	1.42 (2.27)	1.19 (1.83)
After 30 min running	0.71 (1.89)	1.71 (2.29)	3.00 (2.58)

(*P<0.05)

Table 18. The number of back pain sufferers registering pain under the six conditions (n=7)

	Percentage of marathon running speed		
	70%	85%	100%
After 15 minutes running	1	3	4
After 30 minutes running	1	4	6

(*P<0.05)

As shrinkage did not differ significantly between the two groups, their data were pooled for further examination. Re-analysis for effects of running speed and duration of the run on spinal shrinkage was performed by two-way ANOVA. Results show that duration of running exerted a significant effect on the shrinkage which was independent of the running speed. Mean shrinkage for the first 15 min was 3.26 ($\pm$2.78) mm compared with 2.12 ($\pm$1.61) mm for the second 15 min of the run ($P<0.05$). An effect of running speed on shrinkage was again found between the 70%, 85% and 100% conditions, which produced 3.37 ($\pm$2.38), 5.10 ($\pm$1.90) and 7.69 ($\pm$3.69) mm of shrinkage respectively ($P<0.005$). Tukey's Honestly Significant Difference Test (Daniel, 1987) showed that this difference was confined between 100% condition and the slowest speed.

Summary Table:

	Relative Speed (%)			
	70	85	100	mean
Time (min)				
15	-2.19	-2.97	-4.62	-3.26
30	-1.18	-2.13	-3.06	-2.12^{*}
mean	-1.68^{+}	-2.55^{+}	-3.84^{+}	-2.69

($^{*}P<0.05$: $^{+}P<0.005$)

Recent competitive performance times were taken to reflect the relative levels of fitness of the runners. Correlation analysis was performed to determine if running ability or age were related to the amount of shrinkage occurring was during a run. No significant correlation was found between the subjects' marathon or half marathon times and the shrinkage during the first and second 15 min runs, nor with the total shrinkage for the whole run at each speed (P>0.05).

The ages of the subjects ranged from 18 - 51 years. Age was not significantly correlated with shrinkage incurred during running. This applied to all running speeds, both groups of subjects and to the complete sample (P>0.05).

DISCUSSION

The main finding of this study was that spinal shrinkage was increased by an elevation in the running speed when duration is held constant. This result applied both to competing distance runners with chronic low-back pain and asymptomatic runners.

The finding that shrinkage is significantly greater in the first part of the run supports earlier research (Reilly, 1988) and mirrors the characteristic response of the disc 'in vitro' when subjected to loading (Brinckmann, 1988). Though the amount of shrinkage decreased in the second 15 minutes of running relative to the first 15 minutes of running, the absolute level is cumulative (ie the sum of the two values). Reduction in stature may render the disc more vulnerable to injury as it stiffens during a long run. A slowing in rate of height loss in the disc is associated with a reduction in disc height, which increases stiffness and vulnerability to damage (Kazarian, 1975; Brinckman; 1988). The data from the present study are insufficient to predict the amount of shrinkage likely to occur in a complete marathon race.

The absence of a difference in spinal shrinkage attributable to low-back pain symptoms could be explained by the relatively mild level of discomfort suffered by the runners. At the time of carrying out the tests all the runners were still training and competing. Therefore the absence of a difference in spinal shrinkage attributable to low-back pain symptoms could be explained by the relatively mild level of pain suffered by the runners. Runners with pain severe enough to curtail training could not be studied. Further investigation is required to determine whether spinal shrinkage can be used to discriminate between runners with severe low-back pain symptoms and asymptomatic individuals.

Shrinkage was unrelated to the age of thee subjects for any of the running conditions. This finding may not apply to subjects older than the current range of subjects studied, and in whom the disc response to loading might be attenuated (Kazarian, 1975).

In this study all subjects were running at the same relative speed but at different absolute velocities for each running condition. The faster runners who were subjected to a greater absolute loading than the slower runners, did not show greater shrinkage. This suggests resistance to spinal loading in the faster runners due to skill, although an effect of skill was not significant in the study of Leatt et al. (1986).

Recovery of stature following exercise was found to be independent of the amount of shrinkage induced by exercise. This differs from previous findings on recovery from drop-jumping exercises of 7 min duration (Boocock et al., 1990) and is not consistent with experimentation on isolated discs (Kazarian, 1975). In the present study, subjects had been running for 30 min prior to the start of their recovery period in contrast to the short-term exercise regimen used by Boocock et al. (1990). However, Boocock et al. (1990) manipulated the pre-exercise conditions by including a period of unloading using gravity facilitated traction; this affected shrinkage both during exercise and subsequent recovery.

In conclusion this study showed that the presence of low-back symptoms in the runners did not alter the amount of spinal shrinkage incurred during a run of fixed duration. The rate of spinal shrinkage decreased with duration of the run, confirming earlier investigations. In the groups as a whole, shrinkage was found to increase with running speed. Further investigation using a longer duration of exercise is recommended to try to predict the shrinkage during long distance racing. The manner in which these changes might be associated with low-back pain symptoms and age should also be more fully investigated.

6.2 EXPERIMENT 2: DIURNAL VARIATION IN STATURE IN SUBJECTS WITH SEVERE CHRONIC LOW-BACK PAIN

In the previous section the mild low-back pain symptoms in competitive runners were found to have no effect on spinal shrinkage. It was hypothesised that if low-back pain symptoms were to alter the normal rate of spinal shrinkage, symptoms would have to be more severe than those exhibited in the previous section. The purpose of this report is to examine the circadian variation in spinal shrinkage in patients with severe low-back pain.

METHODS

Subjects were eight male patients, aged 38-57 years, on an orthopaedic ward awaiting surgery for chronic low-back pain of discogenic origin (Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry). During this study the same training and measurement criterion as reported for the previous study applied.

The first measurement of stature was made at 0715 hours immediately on rising from bed. Subsequent measurements were taken at 08:15, 09:15, 10:15, 12:15, 14:15, 18:15, and 22:15 hours.

RESULTS

Difficulty was experienced in training patients with severe chronic low-back pain syndromes to use the stadiometer. Only 5 out of 8 patients were able to meet the acceptable reliability level, a standard deviation of less than 0.5 mm over 10 consecutive measures. Diurnal variation in stature among the trained subjects was 7.2 ($\pm$4.8) mm from peak to trough. The range was from 3.1 mm to 13.1 mm. Pearson's product correlation analysis revealed that shrinkage was unrelated to the age of the subjects ($P>0.05$).

DISCUSSION

This study illustrates a potential limitations of stature measurement. Some patients awaiting surgery were unable to maintain a relaxed posture on the stadiometer whilst measurements were taken due to pain. The peak to trough variation in stature of 7.2 mm, recorded on the 5 trainable patients, is approximately 40% of the 19.3 mm previously recorded for normal subjects (Tyrrell et al., 1985). Part of this discrepancy was due to the daily routine being interrupted by bouts of bed rest and other activities which patients adopt to alleviate their pain. However, direct comparison between the two studies is also made difficult by the significantly different ages of the two groups. The chronic low-back pain sufferers were aged 38 - 57 years, whereas the normal subjects used in previouus studies were aged 19 - 21 years. Age affects the structure of the spine and hence its dynamic response characteristics. However, the likelihood is that the low-back pain patients in this age group will have a depressed amplitude of the normal circadian variation because of the duration of bed rest.

Patients with severe chronic low-back pain were unable to relax on the stadiometer suggesting that the shrinkage technique may have limited use in this group of subjects. Thus the usefulness of using spinal shrinkage as an index of spinal loading in back pain sufferers is as yet unclear.

The two groups in this and the previous study, were extreme examples of low-back pain sufferers, those who could still run and those debilitated by pain and awaiting surgery. The runners with mild low-back pain were capable subjects for experimental studies of shrinkage whereas those awaiting surgery were not. The abnormal responses shown by subjects with severe low-back pain suggested that shrinkage may have limited applications in studying this group.

More useful data may be obtained from a population with symptoms in between those experienced by the subjects in the studies to date. An experiment using runners with low-back pain symptoms, still able to run at a reduced speed, would enable comparison to be made with a group of normal runners of the same ability. If both groups ran at the same reduced speed, any differences in response could be observed.

6.3 EXPERIMENT 3: AN INVESTIGATION OF SPINAL SHRINKAGE AFTER A LONG DISTANCE RUN

INTRODUCTION

Previous studies have investigated the effects of distance runs, between 30 and 108 min, on spinal shrinkage (Leatt et al., 1986; Reilly et al., 1988; Section 6.1). Leatt et al. (1986) showed that change in stature during running was primarily related to the duration of the run (Section 3.6.2). Data presented earlier in this study (Section 6.1) showed that most stature is lost in the early stages of running. Shrinkage was shown to reduce in the second 15 min of a 30 min run indicating a deterioration in the shock absorbing properties of the spine (Section 6.1). Previous research did not allow an extrapolation to the shrinkage that would occur during a marathon race, because the rate of shrinkage is not constant throughout the duration of a run (Section 6.1).

Highly trained distance runners incorporate runs of longer duration than previously studied into their training programmes. No attempt has been made to determine the effect of a run of the distance of a marathon race or a long training run (130 min for an elite male competitor) on stature. The physiological demands of a marathon race are different to those of shorter duration due to the depletion of metabolic substrate within the muscle which leads to fatigue (Newsholme and Leech, 1983).

Referring to marathon running, Milvy (1977) stated that "physical activity of this quantity and quality requires an energy expenditure that is both intense and prolonged, and consequently an enormous stress is placed upon the body and its organ systems".

Muscle fatigue was defined by Edwards (1981) as the inability to maintain a given power output. This phenomenon is experienced by many runners around the 20 mile (34 km) mark in the marathon. As a result of fatigue associated with the depletion of muscle glycogen stores during the preceding distance, the runner is unable to maintain pace and slows down, thereby altering the gait pattern. This is commonly referred to as "hitting the wall". Newsholme (1987) stated that the majority of runners in a marathon slow down and often the winner is the one who slows least.

During marathon running the major sources of energy for muscle contraction are blood glucose, hepatic glycogen, muscle glycogen, and free fatty acids (Newsholme and Leech, 1983). The time for which each fuel could theoretically supply the runner are 4 min, 18 min, 71 min free fatty acid sources are both limited in their ability to provide fuel for marathon running. Carbohydrate sources alone are not sufficient to sustain the runner through a marathon. Free fatty acid sources can be mobilised and used only at a slow rate. Fatigue in endurance running may be caused by a decrease in the rate of glycolysis. This occurs when liver and muscle glycogen are almost depleted (Newsholme and Leech, 1983).

The body's total carbohydrates stores could theoretically provide sufficient energy for only 103 min of running. Free fatty acids must therefore provide much of the energy. A highly trained runner will complete a marathon just as muscle glycogen is close to depletion, thus enabling performance to be maintained at as high a proportion of maximum as possible. If the inexperienced runner goes too fast, too early, muscle glycogen levels may be depleted prior to the end of the race. This will leave free fatty acids as the major source of energy and reduce the runner's performance to 60% VO_2 max or less for the remainder of the event. This has also been demonstrated in ultra-distance running (greater than marathon distance), during which glycogen stores become substantially reduced almost to the point of depletion. When this occurs performance drops to a maximum of 50-60% VO_2 max (Davies and Thompson, 1979). This will be visually evident in changes of running gait, with the recruitment of untrained muscle fibres, which may deteriorate into walking in the less fit.

In treadmill running if the belt speed is kept constant, the runner will be unable to slow down as fatigue develops. Running speed could be maintained in two main ways:

i) increasing the force of muscular contraction due to fibre recruitment, thereby maintaining the cadence and stride length relationship;

ii) altering the cadence-stride rate relationship by decreasing stride length and increasing the cadence.

Fatigue whilst running on the treadmill may therefore be indicated by changes in gait. This has been demonstrated by Komi (1984), Komi et al.(1986), Gollhofer and Komi (1987) and Nicol et al. (1991). Electromyography (EMG) may be used to determine the muscular response to prolonged running. Muscle fatigue could be detected using EMG techniques as neuromotor patterns in the muscles alter. Komi (1984) demonstrated that the relationship between integrated EMG and force is shifted to the right when fatigue is induced under isometric conditions between 20% and 90% maximal voluntary contraction (MVC). In concentric and eccentric muscle activity after 40 consecutive contractions, more myoelectric activity was also required for the production of a given level of muscle force.

Gollhofer and Komi (1987) showed that the ground reaction force was dependant on the velocity of running, with higher velocities increasing the force of impact. The time for the support phase of running was also reduced as velocity increased. The rate of rise in EMG activity and the peak amplitude for the knee extensors also increased with the velocity of running. The running velocities used were 3,4,5 and 6 $m.s^{-1}$ (22 $km.h^{-1}$) in non-fatigued conditions. These factors, they concluded, would increase the effectiveness of the stretch-shortening cycle of muscle in lowering and lifting body weight on each impact with the ground.

Komi et al. (1986) examined EMG, kinematic (high speed cinematography) and ground reaction force data, as well as a selection of performance variables, before and after marathon running, after which fatigue would be expected to occur. They found that sprint, static jump, counter-movement jump and 50 cm depth jump performance all decreased. An increase in the eccentric phase of the drop jump (when the quadriceps are elongated after impact) was also noted.

They also reported EMG activity of the leg extensor muscles whilst running at speeds of 3 and 4.5 $m.s^{-1}$ (11 and 16.2 $km.h^{-1}$). The rectified EMG signal showed a lengthening to the right which indicated an increase in ground contact time during the push-off phase. The EMG-force ratio for m.gastocnemius, m.vastus medialis and m.vastus lateralis, and resultant ground reaction force shifted upwards on impact and push-off phases. This was attributed to greater neural activation required after the marathon to produce the same resultant force.

Nicol et al. (1991) attempted to relate EMG (muscle activation) and force platform data to running kinematics. Before and after a marathon race, five endurance athletes performed a treadmill test during which they were filmed. Contact time, flight time, displacement of hip, knee and ankle joints were calculated. An isometric fatigue test included a maximal voluntary torque (MVT) test of the left knee extensors, followed by an endurance test at 60% of maximum. The EMG was analysed during the initial and terminal 2 seconds.

They stated that kinematic analysis did not reveal significant effects of the marathon on treadmill running. However, MVT, isometric endurance and iEMG all decreased by 26%, 38% and 39% respectively, showing evidence of muscular fatigue. Nicol et al. (1991) also found iEMG activity at the end of the endurance test to be positively related to the decrease in endurance time. An increase in contact time and a decrease in flight time were related to a decrease in MVT and a decrease in endurance time. The terminal iEMG of the endurance test was positively related to the change in knee flexion angle at the end of the braking phase on the treadmill run. The terminal iEMG was also positively related to the change in duration of the push-off phase. These finding would appear to contradict the statement that no kinematic changes were observed.

Nicol et al. (1991) ascribed the observed changes to an interaction between neuromuscular and kinematic factors. They concluded that fatigue might reduce impact tolerance with the consequent loss of elastic energy potential and capacity for mechanical work during the push-off phase.

Biological functions other than substrate utilization are also subjected to considerable stress during endurance exercise, and could limit performance under certain conditions. The increased metabolic rate during running is associated with a parallel increase in body temperature, which could lead to hyperthermia and or dehydration. In hyperthermia blood is directed away from the exercising muscle to the skin for cooling which would deprive the muscle of necessary substrate. The extent of this compromised distribution of blood flow depends on the degree to which cardiac output is taxed by the intensity of exercise and the environmental conditions and probably only occurs when cardiac output nears maximal.

A consequence of dehydration is a decreased blood volume and a slowing in the rate at which oxygen, glucose and free fatty acids can be supplied to the muscle (Newsholme, 1987). These problems are more likely to occur in inexperienced runners and in adverse environmental conditions.

It has been demonstrated that neuromotor function is affected by fatigue in marathon running. Such changes may affect gait and alter the transmission of forces to the lower back. The inter-relationships between leg and back muscle activity and spinal shrinkage in marathon running have not been explored. It is postulated that the lower back is more vulnerable to damage towards the end of a long run when motion segment height is reduced.

The aims of this study were to:

i) determine the spinal shrinkage occurring in a run of marathon race distance;

ii) determine the relationship between EMG of the leg and back muscles and changess in cadence during a run of marathon distance;

iii) investigate the relationships between physiological (heart rate, rectal temperature and water volume consumed), physical (cadence variations), and subjective (perception of effort, ratings of back pain) responses to a treadmill run to exhaustion at marathon race pace.

METHODS

Electromyography was used to investigate the role of back and leg muscle fatigue on five male marathon runners whilst treadmill running. The mean marathon time for the runners was 2 h 39 min (30 min). Their experience ranged from an Olympic runner with a best time of 2 h 11 min to a recreation runner with a best time of 3 h and 21 min. None of the runners had a history of low-back pain. The muscles chosen were the left and right erector spinae, and rectus femoris and gastrocnemius unilaterally (Plate 3). These muscles were chosen to provide information on fatigue in the lower back and the main extensors of the lower limb.

The electrodes were bipolar Ag/AgCl surface electrodes with a centre to centre spacing of 6 cm. The electrodes on the leg were placed over the belly of the muscle (Section 2.2.3), after skin impedance had been reduced by removing the dead epithelial cell and oil by light abrasion with sand paper, and cleaning with alcohol. The back electrodes were placed on the trunk at the L3 level (Andersson et al., 1977).

The EMG data were recorded using a multi-channel polygraph (Type 381, NEC San-ei Instruments Ltd, Tokyo, Japan). The four bioelectric amplifiers linked to integrators were set to filter between high-pass and low pass band widths of 10 Hz and 1000 Hz respectively. Raw EMG were collected via a heat pen chart recorder running at 25 $mm.s^{-1}$.

The first record was taken after 5 min when the muscles were assumed to be functioning aerobically, as a steady state condition would exist in the cardio-respiratory system. Subsequently a 30 s burst of EMG activity was recorded every 5 min until exhaustion. The first and final burst of EMG activity were used for analysis.

Photographic enlargements (x3) of the EMG burst were made to aid analysis. Only the positive amplitudes were analysed and a linear envelope was drawn around the EMG trace. The EMG were normalised to the highest peak in dynamic activity recorded during the treadmill run (Yang and Winter, 1984; Section 2.2.3) using a digitizer and software package (Cabri, 1989). This analysis was performed in the Department of Experimental Anatomy at the Free University of Brussels. The area enclosed by the envelope was expressed as a percentage of the area determined by the product of the time and the amplitude of the EMG burst (Plate 4).

A 30 min pilot run at 12 km h^{-1} was performed by one subject to determine the feasibility of the study. No change in EMG waveform for any of the muscles examined was observed. The run was probably too short to cause

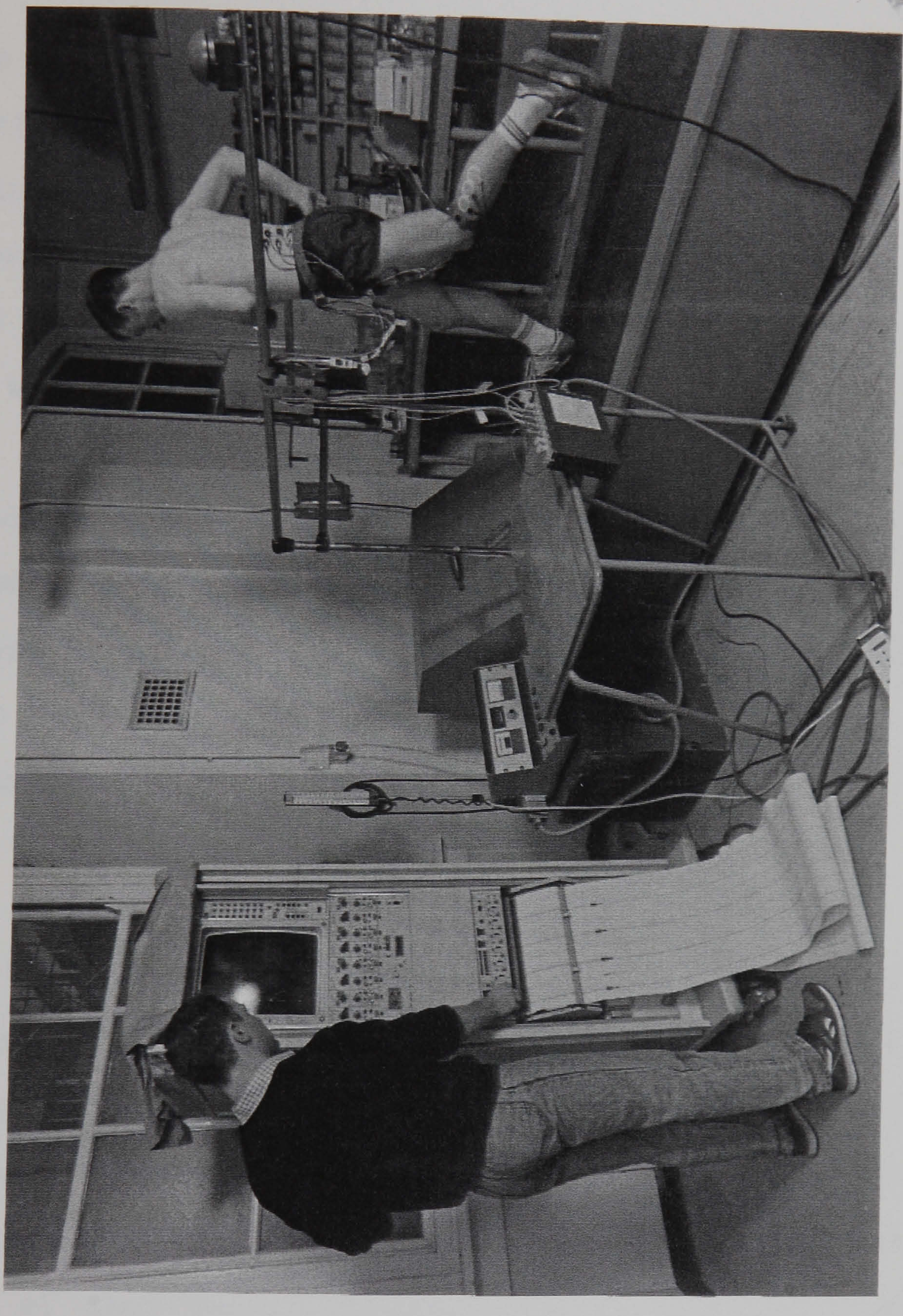


Plate 3. Subject running on treadmill showing placement of electrodes.

fatigue due to glycogen depletion (Newsholme, 1987). All the signals obtained were of a good quality.

In the experimental protocol the speed of the treadmill was initially set at the runner's marathon race pace and the aim was to allow the runner to continue for the full marathon distance. The run was only ended when the runner was unable to continue because the desired pace could no longer be maintained.

The runners were allowed to drink as much water as they desired during the run and the amount consumed was recorded. Body mass was measured before and after the run to determine whether the fluid lost through sweating was replaced.

Heart rate was recorded every 5 min using a short range radio telemetry device (Sports Tester PE 3000). Ratings of perceived exertion (Borg, 1970) and low-back pain ratings (Appendix 4) were also taken every 5 min and in the last minute of exercise. Stride rate was recorded visually, for one minute, every 5 min and in the last minute of exercise.

Spinal shrinkage was measured prior to running and immediately post-running (within 1 minute). The technique previously described in section 3.3 was used. Rectal temperature was measured using an Omron MC-7B

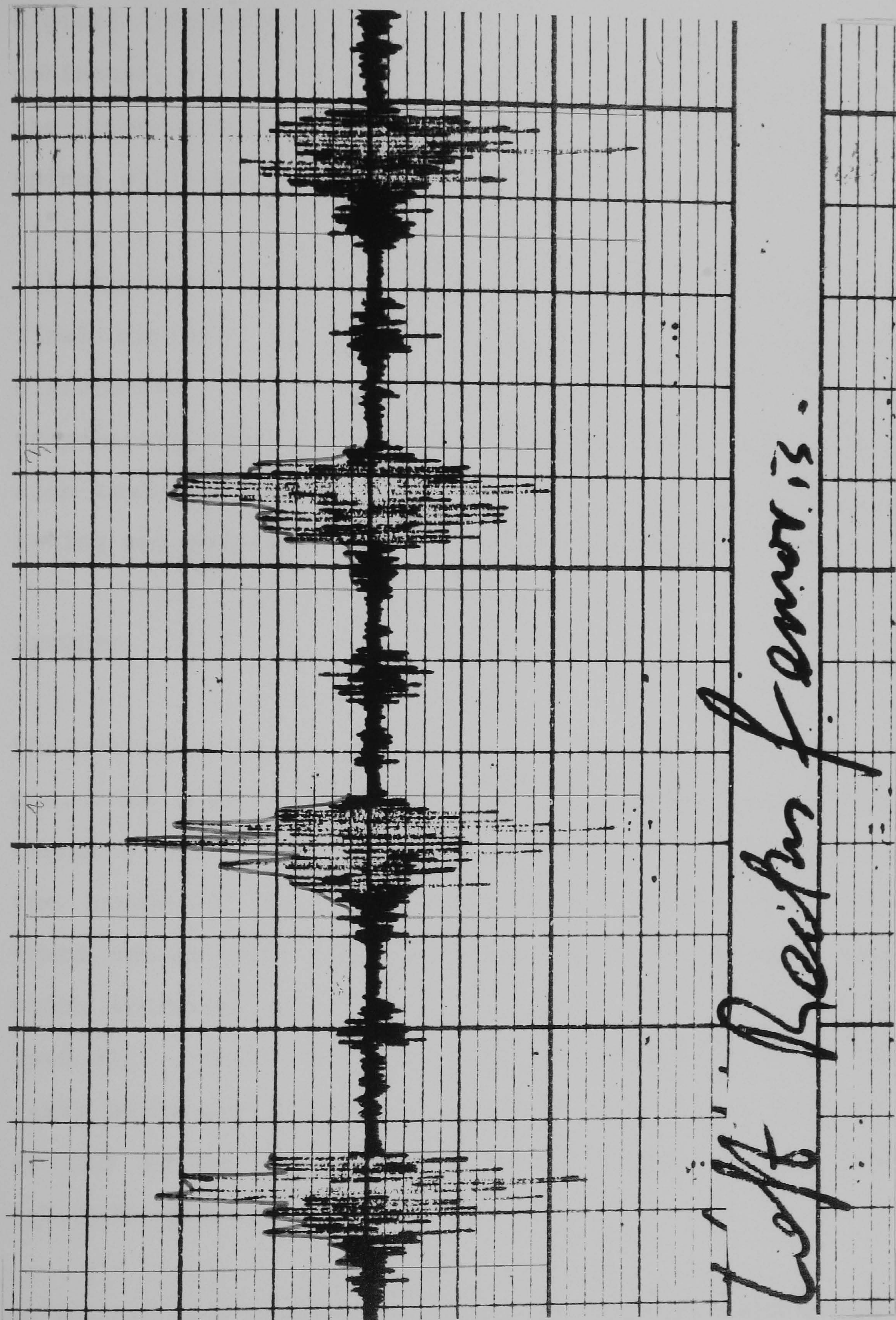


Plate 4. An example of an EMG tracing showing linear envelope.

digital thermometer, inserted 1 cm past the anal sphincter, by the subject. This was done 1 min prior to the commencement of exercise and after measurement of spinal shrinkage post-exercise.

All variables were compared between the fifth and the final minute. A paired t-test was used to determine differences for body mass, heart rate, rectal temperature, EMG activity and cadence. A non-parametric sign test was used for perceived exertion, low-back pain rating and general musculoskeletal discomfort.

RESULTS

The average time to exhaustion for the run was 92 ($\pm$17.5) min. No significant correlation was found between the runner's best marathon time and the time to fatigue on the treadmill ($p>0.05$). Significant differences were found between the fifth and final minutes for body mass which decreased from 64.64 ($\pm$7.47) kg to 62.13 ($\pm$6.84) kg ($p<0.01$). Heart rate increased significantly from 158 ($\pm$13) beats per minute to 177 beats per minute ($p<0.01$), as did rectal temperature from 37.3 ($\pm$0.3)^{o}C to 38.8 ($\pm$0.3)^{o}C ($p<0.001$).

No significant difference in cadence was observed between the fifth and final minutes. The cadence remained virtually unaltered at 89.2 ($\pm$6.5) steps per minute in the fifth minute and 89.4 (±5.3) in the final minute (P>0.05).

The EMG data proved difficult to collect. No satisfactory data were obtained on one subject. Altogether six myoelectric signals were obtained on four subjects. Other four contacts were lost, due to the loss of electrode contacts through sweating. The EMG data suitable for analysis were obtained for the gastrocnemius muscle in one subject, rectus femoris in two other subjects, and right erector spinae and gastrocnemius in the fourth subject. These data were then pooled and analysed together. The mean percentage of the area, defined by the maximal iEMG amplitude during running, multiplied by the time was 34.3 (±5.2)% after 5 min running and 31.5 (±4.9)% during the final minute of running. Thise difference was not significant (p>0.05).

The area under the iEMG curve also decreased when the waveforms of the samples were analysed for the separate muscles groups. The quadriceps area decreased from 32.7 (±6.6)% to 30.7 (±6.4)%; the gastrocnemius area decreased from 35.69 (±1.44)% to 34.23 (±3.1)%; and the erector spinae area decreased from 35.35 (±6.7)%; to 29.86 (±4.4)%. These differences were not significant.

The runners were verified as being without low-back pain as all recorded low-back pain ratings of zero throughout the test run. Perceived exertion increased from 9.6 ($\pm$2.5) to 16.2 ($\pm$1.5) ($p<0.05$). The increase in musculoskeletal discomfort from 2.9 ($\pm$2.0) to 4.6 ($\pm$0.9) was non-significant ($p>0.05$).

Spinal shrinkage data were obtained on 4 of the 5 subjects. One of the runners was unable to record any satisfactory measures of change in stature due to feelings of nausea and faintness when tilted on the stadiometer. The mean shrinkage in the four runners who were measured was 3.93 ($\pm$1.85) mm. The reading taken after the run from the fifth subject, over 5 consecutive measurements ($\pm$1.04 mm), was outside acceptable reliability limits of 0.5 mm.

DISCUSSION

This study highlighted the difficulty of measuring stature in runners after treadmill running at marathon race pace, probably because of the symptoms experienced by the runners. All of the runners complained of nausea and faintness, which occurred whilst trying to maintain a motionless posture on the stadiometer. This posture could have caused blood to pool in the legs reducing central venous pressure and therefore venous return to the heart and circulation to the brain. This situation was probably exacerbated by the loss of 2.51 kg of fluid via sweating. The spinal shrinkage observed was less than found for shorter duration runs (Leatt et al., 1986; Reilly et al., 1988; Section 6.1). It may be that the data are unreliable due to poor postural control. The inability of the subjects to relax on the stadiometer after the run, and the consequent large standard deviation render these results questionable. Compared to the values for short duration runs, shrinkage of 3.93 mm probably underestimates the true shrinkage.

The methodological problems encountered in measuring change in stature could perhaps be overcome by modifying the stadiometer. Other groups (Krag et al., 1990; Magnusson et al., 1990) have developed stadiometers which measure whilst the subjects are either recumbent or seated. Both of these techniques offer the possibility of reducing or eliminating orthostatic response which interfered with stature measurement in the upright posture.

The EMG burst recorded in the last stages of running showed no evidence of fatigue when compared to that after 5 min of running. The limited data collected allowed comparison of the area under the linear envelope after 5 min of running and in the last minute of exercise. The initial analysis included the iEMG data collected for the gastrocnemius in one subject, rectus femoris in two other subjects, and right erector spinae and gastrocnemius in the fourth subject (n=12). The different muscle groups may have been of different fibre composition and would therefore fatigue at different rates.

The incomplete EMG data reflect technical problems in securing the electrodes to the skin, in all the muscles monitored, given the profuse sweating of the subjects. Previous studies on marathon runners over the full marathon distance did not attempt to record muscle activity continuously, rather electrodes were removed after pre-run testing and replaced after the run (Komi et al., 1986).

Komi et al.(1986) demonstrated that rectified EMG activity increased in the m.gastrocnemius, m.vastus medialis and m.vastus lateralis. When related as a ratio to ground reaction force data, during impact and push-off phases of the running support phase, the ratio shifted upwards indicating greater neural activation was needed after the marathon to produce the same force. These changes were greater for the support phase than the impact phase. Komi et al. (1986) attributed this to a decreased ability of the leg extensors muscles to sustain repetitive impact loads, causing the muscle to lose its recoil characteristics utilised in the stretch-shortening cycle.

Although the iEMG showed no significant evidence of muscle fatigue, the runners all stopped running due to exhaustion prior to their expected time, based on their marathon performance. The mean time to exhaustion was 92.0 ($\pm$17.5) min. This was a considerably shorter duration than would be expected for a marathon run and may not have been sufficiently prolonged to cause glycogen depletion and the expected change in gait. That gait did not alter was verified by the observation that cadence remained unaltered throughout the run. It is possible that dehydration and heat stress caused the cessation of running. The significant loss of body mass through dehydration and increment in heart rate (19 beats.min^{-1}) indicated that these factors are the more probable determinants. Support for this rationale comes from the perceptual data. The subjects rated the exertion of the exercise significantly harder in the last minute of the run than after 5 min (16.2 and 9.6 respectively). The level of exertion approaching 'very hard' may be intolerable in a non-competative context.

The finding that the time to exhaustion was shorter than expected could be accounted for by the runners not being at their optimum level of fitness for a marathon race. It is possible too that lack of motivation, due to the run being performed outside race conditions, was a contributory cause of subjects desisting.

The problem of runners not completing the full distance of the marathon run rendered it unlikely that fuel depletion was the main cause of fatigue. It is perhaps a combination of the indoor environment (lack of cooling and evaporative heat loss), the use of the treadmill (not allowing the runner to slow down) and the non-competitive context which were the major contributors to the earlier than predicted end to running. The work of Komi et al. (1986) was performed after a marathon race, conditions familiar to the runner, allowing the distance to be completed. Komi et al. (1986) and Nicol et al. (1991) showed increased contact during the support phase and decrease flight-time after marathon running. They also found an increase in the EMG-muscle force ratio which they hypothesised would alter the shock absorbing qualities of the muscle. It seems simulation of marathon running in a laboratory context falls well short of realistic competitive conditions.

Further work is required to determine the amount of spinal shrinkage caused by the marathon run. This may best be achieved by altering the design of the stadiometer to reduce the orthostatic effects of the upright posture. Useful data might be obtained from a run of shorter duration than the marathon, during which measures of stature are taken at numerous intervals. This would allow a power function to be fitted to the data from which shrinkage over the marathon distance could be estimated.

Shrinkage data should be examined in relation to changes in the stretch-shortening of the leg extensors muscles. Reductions in efficiency of the of the stretch-shortening cycle may reduce the ability of the muscles to dissipate shock loading during running and therefore affect spinal loading. The EMG data should be collected in runs of marathon duration. This could either be done by manipulating the treadmill run and indoor environment to imitate more closely normal running conditions, or during a marathon race via radio telemetry. The methodological problem of reducing insecure electrode fixation due to profuse sweating, by more secure adhesion should first be addressed.

6.4 EXPERIMENT 4. PHYSIOLOGICAL AND SPINAL RESPONSES TO CIRCUIT WEIGHT-TRAINING

INTRODUCTION

Traditional weight-training using heavy weights and few repetitions improves muscular strength rather than cardiorespiratory fitness (Nagle and Irwin, 1960). Circuit weight-training (CWT) was developed for promoting aerobic as well as muscular fitness in athletes (Adamson, 1956). The aim of CWT is to stress the cardiovascular system by requiring the participant to lift weights, varying the muscle groups engaged to avoid local muscular fatigue, whilst maintaining the load on the cardiovascular system. A typical circuit consists of 8-10 exercises, each with 10-15 repetitions performed 3 times and lasting a total of about 20 min. Early studies into the effects of CWT failed to demonstrate its potential as a means of improving aerobic power (Nagle and Irwin, 1960; Allen et al., 1976).

Later studies indicated that CWT did improve aerobic power but it was not as effective as more conventional modes of exercise such as running, swimming and cycling. Pollock et al. (1969) and Pollock (1973) reported increases in $\dot{V}O_2max$ of between 17% and 35% from running programmes over 16 to 20 weeks, compared with 4% to 14% increases in CWT over 8 to 10 weeks. Gettman et al.

(1978) compared the physiological effects of CWT and running regimens over a 20 week period. Despite the lengthy duration of this study the subjects doing CWT showed only a 3.5% improvement in $\dot{V}O_2max$, compared with a 17% increase for the runners. These results confirmed that CWT provided a less effective aerobic training stimulus than running. This difference may have been due in part to the use of a treadmill test for assessment of aerobic power, instead of a test more specific to the muscles trained in CWT, a difficulty acknowledged by Gettman and Pollock (1981). However, non-specific tests such as rowing have shown the same results as treadmill tests i.e that running is superior to CWT for aerobic training (Gettman and Pollock, 1981).

During CWT the heart rate is stressed to a greater degree than the $\dot{V}O_2$ when each is expressed as a percent of the maximal values. Observations have ranged from 69 - 84% of HR max and 38 - 49% of $\dot{V}O_2$ max (Wilmore et al., 1978; Gettman, 1978; Hempel and Wells, 1985). The static muscular load in CWT is greater than in swimming, running and other modes of aerobic exercise and this may contribute to the elevation of the HR-$\dot{V}O_2$ ratio during CWT. Therefore, the HR during CWT would be deceptively high and may not be a valid indicator of cardiorespiratory loading. The $\dot{V}O_2$ during CWT is comparatively low and does not reach the required training threshold according to the American College of

Sports Medicine (ACSM) guidelines (1986). These specify that the following conditions should be met:-

i) heart rate should reach 60 - 90% (estimated from the equation 220-age) and VO_2 reach 50 - 85% of their maximal values;

ii) the duration of the exercise should be 15 - 60 min;

iii) the frequency of training should be 3 - 5 times per week.

Gettman and Pollock (1981) claimed that CWT has a role in the muscular training of athletes, as a supplement to an aerobic training programme. Reilly and Thomas (1978) demonstrated that use of an ergonomically designed multi-station system can induce physiological responses compatible with an aerobic training stimulus. Such observations raise the possibility that the circuits employed in the study of conventional CWT were poorly designed or improperly conducted.

As well as the physiological load imposed by CWT, compressive loading of the spine is also incurred (Leatt et al. 1986). Repeated or sustained compressive forces lead to narrowing of the intervertebral discs, which increase the stiffness of the disc and its vulnerability to damage. These changes in vertebral dimensions combine to reduce motion segment heights which are reflected in changes in stature (Hirsch, 1955; Kazarian, 1975; Kramer, 1977; Brinckmann et al., 1983).

Leatt et al. (1986) and Wilby et al. (1987) studied the changes in stature caused by CWT. The CWT routines used only free-weights and exercises were deliberately chosen to load the spine directly or engage the back muscles. This study reverted to a more typical regimen employed for purposes of aerobic training. Spinal responses to CWT using a combination of free-weights, weight-training machines and unresisted truncal exercises (sit-ups and back extensions) have not previously been investigated.

Two studies were designed to:-

i) assess the intensity of exercise during a typical CWT regimen by examining the physiological and perceptual responses to performances of three consecutive circuits, and determine how these responses varied between circuits;

ii) study the physical responses to CWT using spinal shrinkage as an index of spinal loading, and relate the physical to the physiological and perceptual responses;

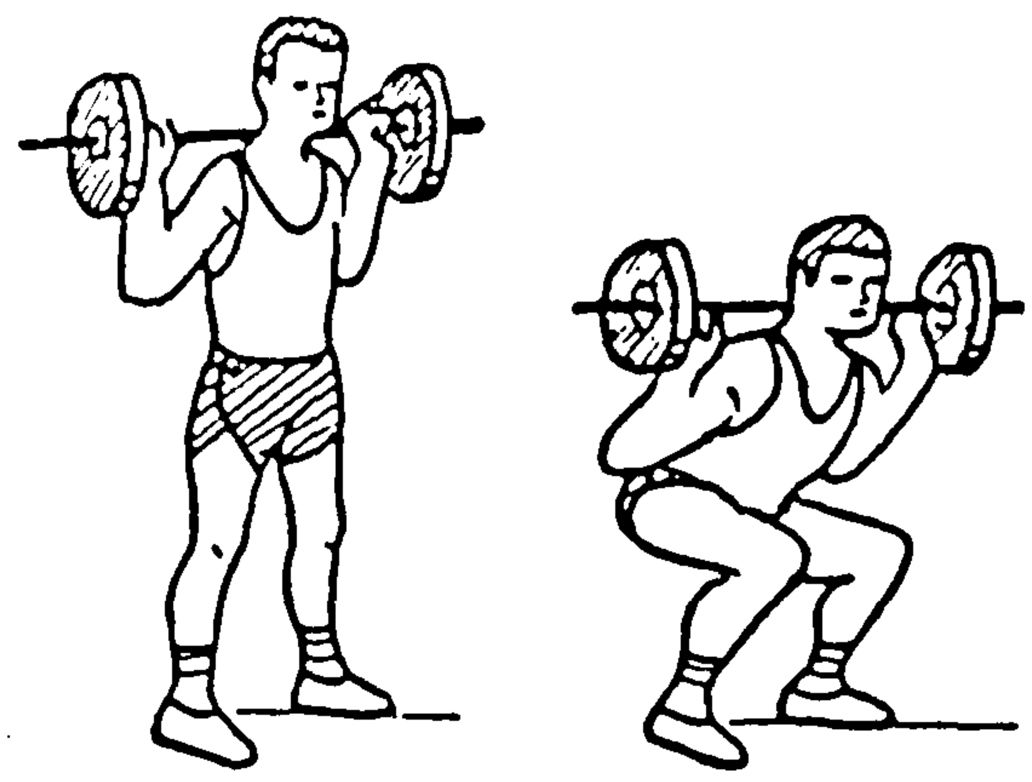
It was hypothesised that the physiological and perceptual responses to CWT are correlated with spinal loading.

METHOD

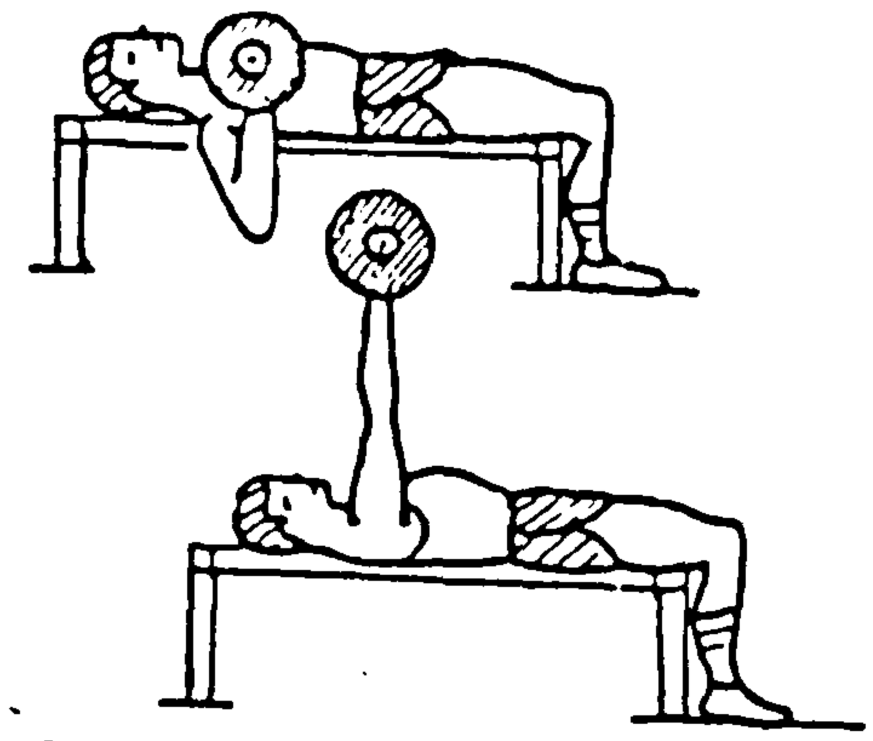
In both studies the CWT consisted of nine exercises

(Figure 6) per circuit, the circuit being performed three times. The exercises were performed according to this order:- the squat, bench press, lateral pull down, seated leg press, sit-up, seated row, dead-lift, shoulder press and back extension. The sequence was designed to maintain a high exercise intensity while avoiding local muscular fatigue. The lateral pull down, seated leg press, seated row, and shoulder press were conducted using a multi-gym (Reilly and Thomas, 1978) the design of which largely determines the performance technique. The subjects were coached in the correct exercise techniques prior to the experiment. This entailed demonstration of each exercise, followed by observation of the subject and correction of faulty technique. At this time the subjects' maximal lift, or one repetition maximum (1 RM), was determined for each lift, apart from the sit-up and back extension which did not use measurable weights.

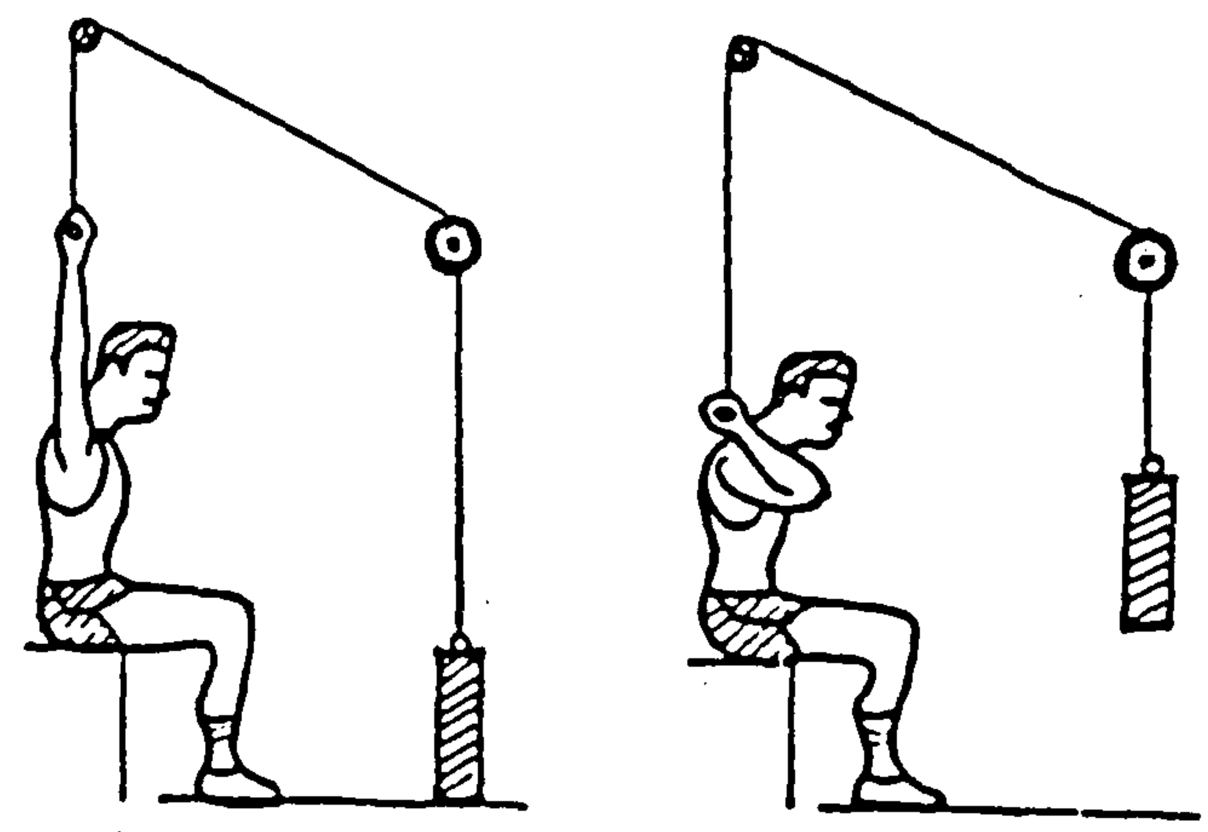
The loading for the circuits was set at 40% 1 RM for each exercise, leg exercises being repeated 15 times and arm and trunk exercises 10 times. The higher number of repetitions for leg exercises was to help stimulate the oxygen transport system by using large muscle groups more than small muscle groups. The subjects were instructed to perform the repetitions at their own pace with a volitional recovery period of no more than 30 s between each exercise and between consecutive circuits. A greater recovery interval than this has been shown to



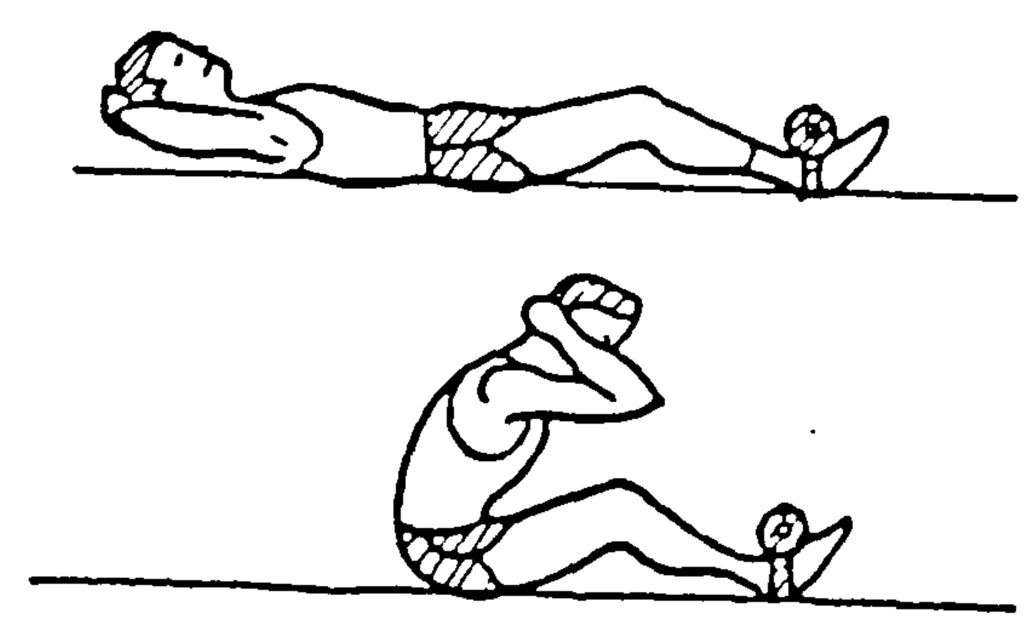
1. Squat



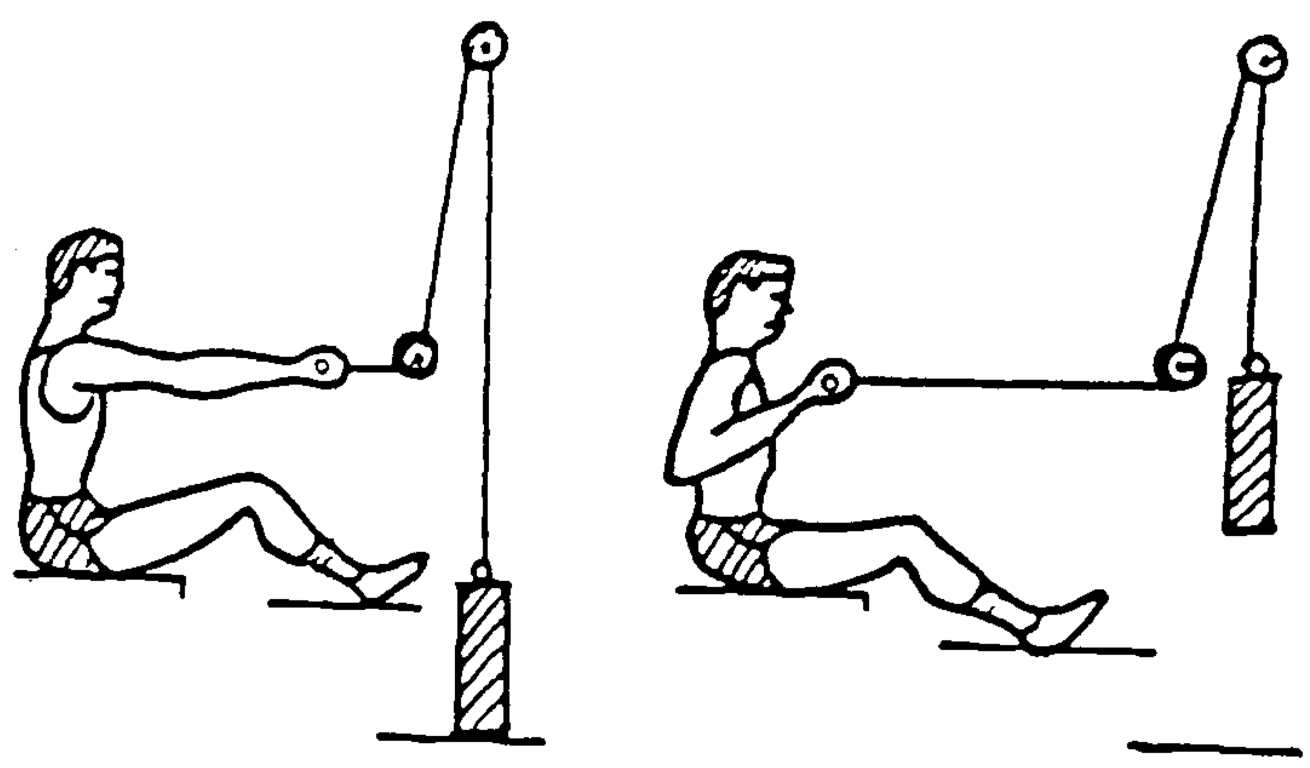
2. Bench Press



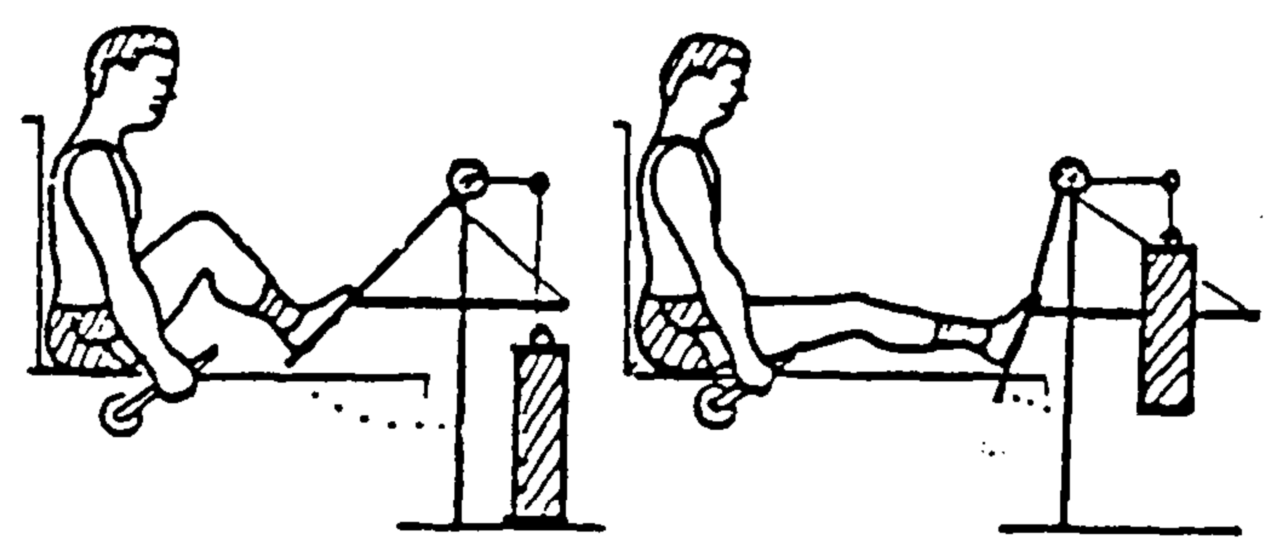
3. Lateral Pull Down



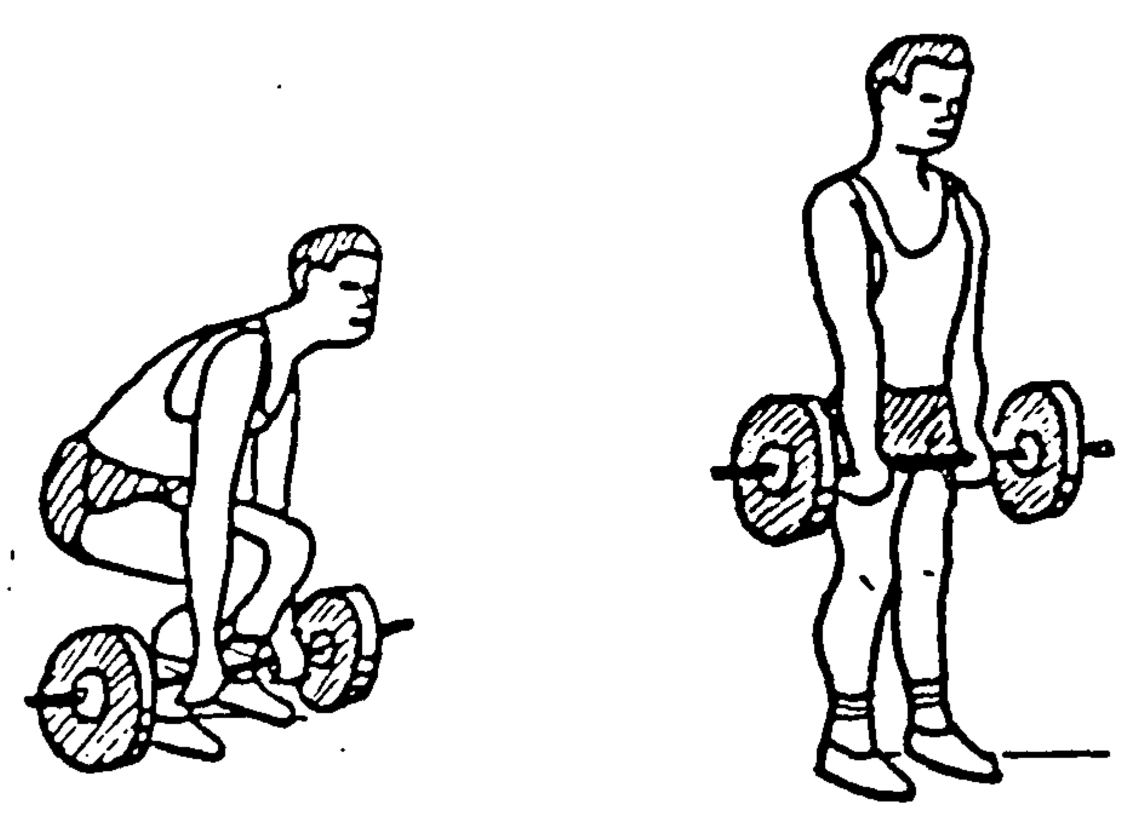
4. Sit-Up



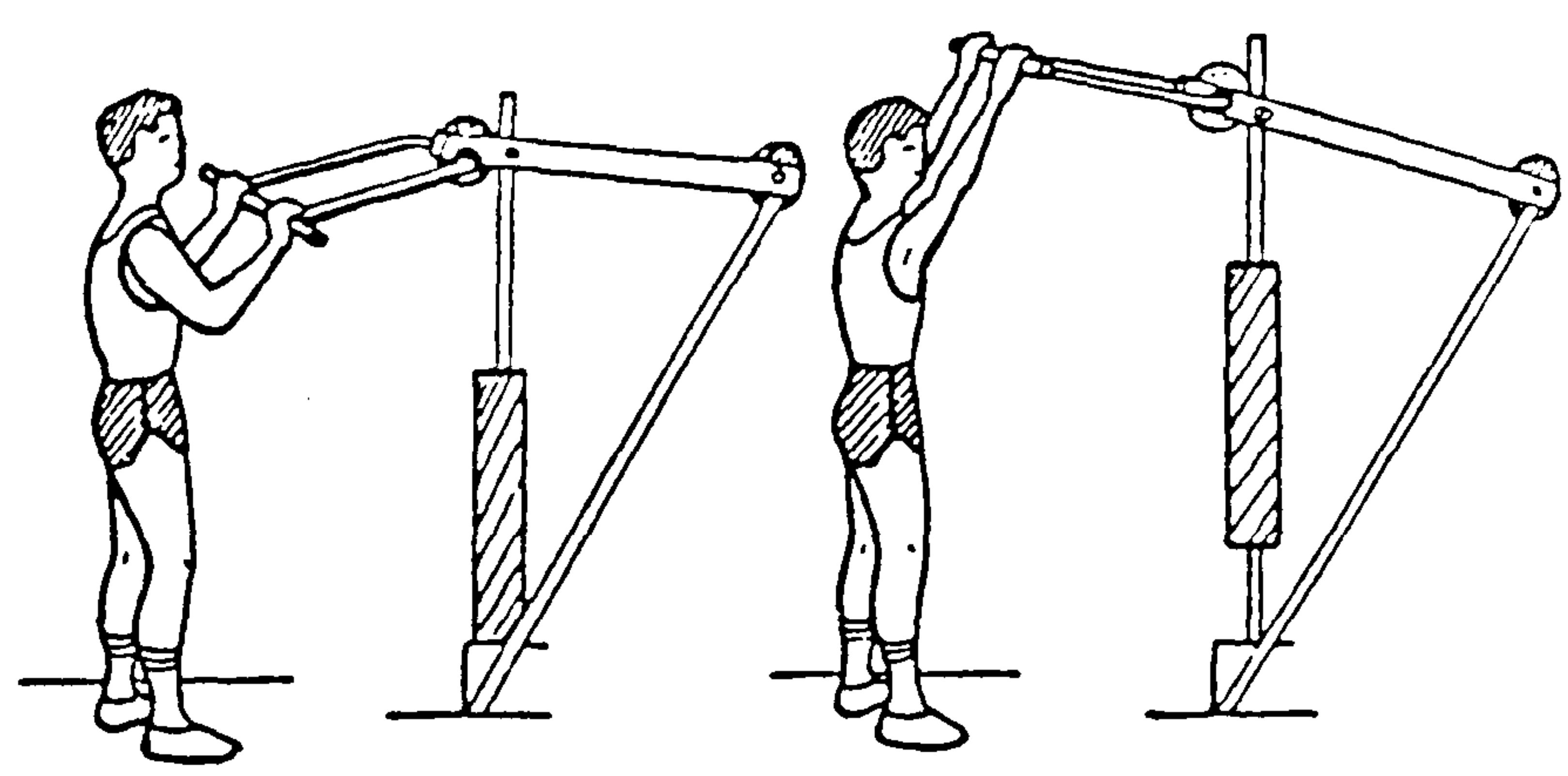
5. Seated Row



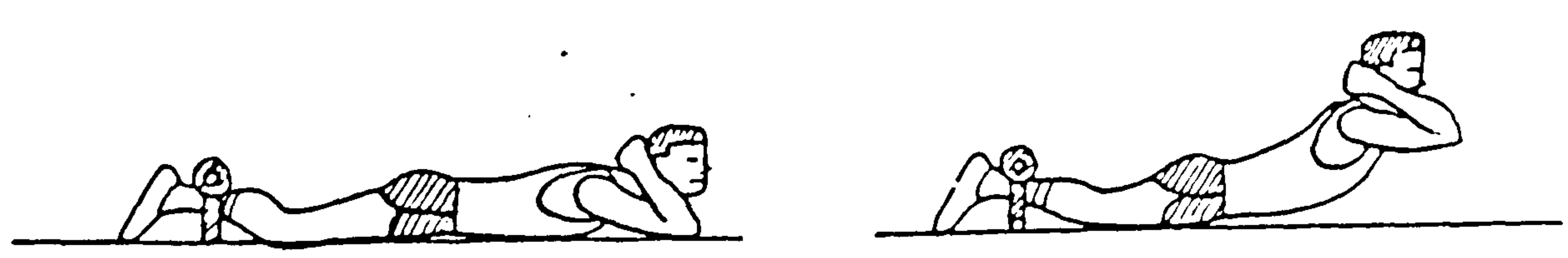
6. Leg Press



7. Dead Lift



8. Shoulder Press



9. Back Extension

Figure 6. The exercises incorperated in circuit weight training in the order performed.

reduce the intensity of exercise to a level at which the training effect is reduced (Gettman and Pollock, 1981).

All subjects were Sports Science undergraduates with no history of low-back pain. All were habitually active in sport and athletics and had experience of using weight-lifting techniques. Subjects were requested to follow their normal routine on experimental days, avoiding strenuous activity.

METHODS: PHYSIOLOGICAL RESPONSES TO CWT

Subjects were 10 males aged 21.4 (2.9) years, body mass 71.4 (8.7) kg and height 176 (10) cm. Prior to the experiment HR max and VO_2 max were measured during a continuous, incremental, maximal treadmill test, using an on-line respiratory gas analysis system (P.K.Morgan Ltd, Rainham). The treadmill speed was initially set at 7.5 km h^{-1}, rising by 2.5 km h^{-1} every two minutes up to 17.5 km h^{-1}, after which the gradient rose by 2.5% until exhaustion was reached. Blood lactate (La) was determined from finger prick blood samples taken at the end of each incremental rise using an enzymatic method (Gutman and Wahlfield, 1972). The value obtained immediately post exercise was deemed the peak La .

Throughout CWT expired air was collected using the Douglas bag method (Plate 4). Minute ventilation (VE) was measured using a Parkinson-Cowan gas meter, O_2 content of expired air with a Servomex analyser (Sybron-Taylor, Crowborough) and CO_2 with an infra-red IRGA 120 analyser (Seiger). The VO_2 was calculated according to Consolazio et al. (1963). Heart rate was measured throughout CWT using a short range telemetry device (Sport-tester PE3000).

A finger prick blood sample was taken at the end of each circuit to analyse for blood lactate (La) H(enzymatic method). Subjects' ratings of perceived exertion (RPE) (Borg, 1970) were recorded at every change of exercise to determine the general perceptual response to exercise. Low-back pain ratings (LBP) were also taken at every change of exercise to determine whether the regimen induced low-back pain in response to loading.

METHODS: CWT AND SPINAL LOADING

A second study examined the effect of the same CWT regimen on spinal loading as indicated by change in stature (shrinkage). The total load handled in each circuit was 3126 (503) kg. This was determined by multiplying the weight constituting 40% 1 rm for each exercise by the number of repetitions for each exercise. Testing took place at 09:00 hours to control for diurnal variation in stature (Tyrrell et al., 1985). Eight healthy males, mean age 23.3 (4.4) years, body mass 76.4

(8.1) kg and height 179 (4) cm were subjects. Shrinkage was measured using a purpose-built stadiometer as described by Boocock et al. (1986). Subjects were trained on the stadiometer to ensure reliability of subsequent measurements. A standard deviation of less than 0.5 mm over 10 consecutive measures was deemed to indicate an acceptable level of reliability. All subjects achieved the required level, obtaining an average standard deviation of 0.40 ($\pm$0.09) mm. Stature was measured immediately prior to and after CWT. The heart rate (HR) and perceived exertion (RPE) were measured throughout the circuit. An eleven point pain scale with '0' representing no pain and '10' the worst pain imaginable, was used in rating low-back pain (LBP).

Changes in physiological variables between the 3 circuits were analysed using two-way ANOVA. Changes in perceptual responses were analysed using Friedman's two-way ANOVA by ranks. Pearson's correlation and Spearman's rank correlation analysis were used to determine the relationships between spinal shrinkage, the physiological and perceptual variables and time to complete the circuit. A probability level of 0.05 was set for statistical significance. All data analysis was performed using MINITAB Statistical Software.

Plate 5. Collection of expired air during CWT using the Douglas bag method.

RESULTS: PHYSIOLOGICAL RESPONSES TO CWT

The results of the incremental treadmill test performed prior to the commencement of the CWT study showed that the mean values for HR max and $\dot{V}O_2$ max were 195 ($\pm$13) beats min^{-1} and 59.7 ($\pm$4.8) ml kg^{-1} .min^{-1} respectively. Peak La was found to be 14.3 ($\pm$3.5) mM (Table 19).

Mean time to complete three circuits was 17.8 (+1.4) min (Table 19). Two-way ANOVA showed that the time to complete the first circuit was less than for the second and third circuits, 5.6 ($\pm$0.4), 6.1 ($\pm$0.7) and 6.1 ($\pm$0.5) min ($p<0.05$).

Mean HR and $\dot{V}O_2$ for the circuit were 135 ($\pm$18) and 30.1 ($\pm$7.0) ml kg^{-1} min^{-1}. These values were 69% of HR max and 50% $\dot{V}O_2$ max. The HR increased significantly between circuits ($p<0.05$); in contrast VO_2 did not alter (Table 19). Mean $\dot{V}E$ and La values were 52.7 ($\pm$14.5) l.min-1 and 6.9 ($\pm$3.6) mM. The increase in VE across the regimen was non-significant but La did increase from circuit 1 to circuit 3 ($p<0.01$). The HR max and $\dot{V}O_2$ max were unrelated to time for CWT performance. Peak La (recorded after a $\dot{V}O_2$ max test run on a treadmill) was inversley correlated with time to complete the third circuit and La level in circuit 3, r=-0.64 and r=0.70 respectively. Time to complete the CWT was related to time taken to complete circuit 1 and La in circuit 1 (r=0.81 and r=-

0.80) and to mean HR, $\dot{V}E$, $\dot{V}O_2$ and La over the whole CWT ($r=-0.64$, -0.80, -0.74 and -0.77 respectively: $p<0.05$).

Table 19. Physiological responses to circuit weight-training (Study 1)

(Mean and SD are presented; n=10)

	CIRCUIT 1	CIRCUIT 2	CIRCUIT 3
TIME (min)	5.6 (0.4)	6.1 (0.7)	6.1 (0.5)
HR (beats.min.$^{-1}$)	122 (18.0)	136 (17.0)	149 (19.0)
$\dot{V}E$ (l.min^{-1})	44.5 (11.0)	52.5 (14.3)	61.1 (23.0)
$\dot{V}O2$ (ml.kg^{-1}.min^{-1}.)	27.4 (6.7)	29.6 (7.5)	33.4 (12.1)
La (mM)	4.8 (2.6)	6.9 (4.0)	8.8 (5.0)
RPE	9.9 (1.2)	10.9 (1.7)	11.5 (1.6)

RESULTS: CWT AND SPINAL LOADING

The mean time taken to complete CWT was 17.4 (±1.3) min. The increases in time for each successive circuit (Table 20) were not significant. The mean HR for circuits 1, 2 and 3 increased progressively ($p<0.005$) as with the first study (Table 20). The RPE levels increased between circuits ($p<0.05$) but LBP ratings did not alter significantly. The mean shrinkage caused by CWT was 2.5 (±1.5) mm. Individual shrinkage values were unrelated to the total weight lifted during the circuit or the time taken to complete the CWT. Nor was there any significant correlation between shrinkage and HR, RPE or low-back pain ratings.

Table 20. Physiological and shrinkage responses to circuit weight-training (Study 2). (Mean and SD are presented; n=8)

	CIRCUIT 1	CIRCUIT 2	CIRCUIT 3
TIME (min)	5.7 (0.4)	5.8 (0.6)	6.0 (0.7)
HR (beats.min.$^{-1}$)	115 (14.0)	139 (14.0)	147 (16.0)
RPE	12.2 (1.6)	13.4 (1.6)	14.5 (1.8)
LBP	0.9 (1.1)	1.0 (0.9)	1.2 (1.4)
Shrinkage (mm)			2.5 (1.4)

DISCUSSION

The target heart rate threshold (60% max) for stimulating the oxygen transport system, according to the ACSM (1986), was calculated to be 117 beats min^{-1} in the first study. This was achieved in the first circuit. The corresponding target $\dot{V}O_2$ required to achieve a training effect for aerobic improvements was 30 ml kg $^{-1}$ min^{-1}. This was reached only in the last of the three circuits. Provision of an aerobic training stimulus using the current circuit would require the addition of a further circuit.

The large difference in the relative values between heart rate and oxygen uptake found during CWT in this study (69% and 50% max respectively) confirms the findings of previous authors (Wilmore et al., 1978; Hempel and Wells, 1985). The CWT exercises incorporated arm as well as leg work, and static muscular loads which may have caused the observed disproportionate increase in the HR relative to $\dot{V}O_2$. The inclusion of more repetitions in the leg exercises than in the arm exercises did not offset the increase. Heart rate values for arm exercise, and combined arm and leg exercise, are higher than for leg exercise alone at a given $\dot{V}O_2$ (Astrand and Rodahl, 1986). The reduced muscle mass associated with arm exercises reduces the training stimulus for the oxygen transport system. This might explain the low improvements in cardiorespiratory fitness found after other programmes for CWT (Pollock et al., 1969; Pollock, 1973; Gettman et al., 1978).

The average La value of 6.9 (3.6) mM implies a large contribution from anaerobic metabolism to energy expenditure which may in part be due to the use of small muscle groups of the arms and shoulders in CWT. Allen et al. (1976) stated that the high intramuscular pressure found during weight-training exercise restricts blood flow and causes active muscle to rely more on anaerobic sources of energy. It may reduce venous return whilst performing the exercise, lowering stroke volume for a given heart rate, and thereby reducing the training stimulus to the heart.

The work rate slowed between circuit 1 and circuit 3 in both studies though this difference was only significant in the first study. This demonstrated that subjects were unable to maintain the pace they initially set throughout the circuit and the constant work-rate normally associated with more traditional forms of aerobic exercise was not achieved. The work rate in performing the circuits was self-paced and it seems that the overall pace was determined early in the regimen. This was shown by the high correlation between time to complete the CWT and time taken to complete circuit 1. The La in circuit 1 was inversely related to CWT time indicating that the subjects who exhibited a high degree of anaerobic metabolism early in CWT maintained a fast pace throughout the circuit. Mean HR, $\dot{V}E$, $\dot{V}O_2$ and La over the whole CWT were also inversely related to time to complete CWT. This also indicates that subjects who could tolerate a high intensity early in the CWT were able to maintain a faster pace and finish more quickly despite the rise in heart rate and blood lactate between circuits. Conversely, it could be deemed that the high physiological responses were due to a high intensity of exercise from the start.

Spinal shrinkage was 2.5 (1.5) mm, this being less than half of the magnitudes reported by Leatt et al. (1986) and Wilby et al. (1987), 5.62 mm and 5.4 mm respectively. The CWT regimen used in this study was of shorter duration than those used by Leatt et al. (1986) and Wilby et al. (1987). It is unlikely that the shorter duration of exercise accounts for all the difference in shrinkage, as most shrinkage in response to exercise has been shown to take place in the early part of the exercise period (Section 6.1).

It is likely that the reduced shrinkage observed in this study, compared with that found by Leatt et al. (1986) and Wilby et al. (1987) is due to the difference in circuit design. The previous studies used free-weights and the exercises were specifically chosen to load either the spine directly, or engage the muscles of the back. All of the exercises involved either flexion and extension of the spine whilst pushing or resisting a weight or direct axial compression of the spine whilst pushing or resisting weight. The CWT in this study differed in that a combination of free-weights, weight-training machines and unresisted truncal exercises which lessened the load on the spine was used. The lateral pull down, seated leg press and seated row, were performed whilst seated on 'multi-gym' equipment which may reduce synergistic muscle action required to maintain posture and technique when using free weights. The bench press using free weights was performed supine and this posture would help reduce spinal loading. Thus the combination of exercises used in this regimen of CWT caused less shrinkage than observed using free weights alone. Further ergonomics analysis of CWT exercises could entail a biomechanics modelling approach to estimate the loads on the lumbar spine during each exercise. These calculations could then be related to the load as indicated by spinal shrinkage.

The finding that shrinkage was unrelated to the time taken to complete the CWT, HR, RPE or low-back pain ratings suggests that shrinkage was independent of the physiological stress of the circuit. Nor was there a correlation with the total load handled. The observations fail to support the hypothesis that shrinkage during CWT is related to physiological responses. It is possible that shrinkage is related to individual diferences in handling technique or coping with the physical load, which may also account for some back injuries.

The main observations of this study were that:-

1) Physiological strain increased with the duration of the CWT but overall this regimen may not provide the aerobic training stimulus.
2) The spinal shrinkage was independent of the physiological strain and perceptual responses in CWT.

In order to reduce spinal loading and maximise the aerobic training effect of CWT it is recommended that:-

i) The length of any CWT routine should be chosen to ensure that the target intensity levels are maintained for 15 min. This would require the addition of a fourth circuit, bringing the total time to 23-24 min.

ii) Circuits should be comprised of more exercises involving larger muscle masses than in the present study.

iii) The use of 40% 1 RM to set the weight to be lifted may be inappropriate as it may overload the smaller muscle groups by occluding blood flow and inducing anaerobic metabolism. A lower percentage of 1 RM with an increase in the number of repetitions is preferable.

iv) Combining weight-training machines, truncal and free-weight exercises is recommended for training as this combination may decrease spinal loading.

v) Although CWT would seem to have marginal value on its own as a stimulus for aerobic training, it may be a useful adjunct to training for players of team games with mixed anaerobic and aerobic components.

7 INTERVENTION STUDIES

7.1 INTERVENTION STUDY 1: AN EVALUATION OF WARM-UP AND WARM-DOWN PROCEDURES, BEFORE AND AFTER RUNNING, USING SPINAL SHRINKAGE

INTRODUCTION

The McKenzie procedure, consisting of a series of spinal mobility exercises, has been proposed as a method of preventing low-back pain (Mckenzie, 1980). The exercises can be adapted for use by athletes as a pre-exercise routine. This study compared effects of a modified McKenzie mobilisation procedure and a conventional warm-up on shrinkage in stature incurred during a 20 min run and followed through the comparisons into the recovery period.

Warm-up and warm-down routines are often advocated to reduce injury risk during exercise (Shellock and Prentice, 1985). Spinal mobilization exercises included as part of warm-up and warm-down regimens may mitigate the effects of spinal loading, decrease disc stiffness and reduce injury risk. It is therefore, necessary to explore whether pre-exercise mobilization procedures can influence the rate of spinal shrinkage.

METHODS

Eight healthy males, (mean age 28.0 (8.1) years) acted as subjects. The test protocol comprised a 10 min period of sitting to control for prior activities which may have caused spinal loading. This was followed by a 10 min period during which a warm-up period, a 20 min run at 12.5 km h^{-1}, a 10 min warm-down period and 10 min seated recovery. Three treatments were employed, subjects being randomly assigned to either the control (sitting with the lumbar spine supported in extension), McKenzie mobilisation or conventional warm-up/warm-down groups. These conditions determined the activity performed during warm-up and warm-down periods. The exercises performed in the warm-up session were repeated in the warm-down session. Stature was measured before and after a 10 min control period of sitting pre- exercise, after a 10 min warm-up, after a 20 min run, and after a 10 min warm-down.

The McKenzie mobilisation procedure involved the following exercises:- lying lumbar extension; lying lumbar flexion, (both knees to chest); cat stretch, lumbar flexion and extension; lying lumbar flexion, (single knee to chest); and standing lumbar extension (Figure 7 A). The conventional exercises comprised the following: double shoulder rotation; trunk twists; alternate lunges; toe touching; and alternate calf stretches (Figure 7 B). Each warm-up and warm-down routine lasted for 10 min consisting of 6 repetitions per minute.

Changes in stature were measured using the previously described technique (Boocock et al., 1986). Each runner underwent training on the stadiometer, ensuring reliability of subsequent measurements. A standard deviation of less than 0.5 mm over 10 consecutive measures was used as criterion that the subject was adequately trained. All subjects achieved the required level, obtaining an average of 0.43 (±0.06) mm in 2 (±1) training sessions, with 43 (±29) measures, taking 43.8 (±38.8) min. During this period flexibility was determined using a sit and reach test session.

Subjects were requested to follow their normal routine on the day of the experiments and refrain from strenuous activity. Each visit was at 13:00 hours to control for circadian variation in stature (Tyrrell et al., 1985; Wilby et al., 1987).

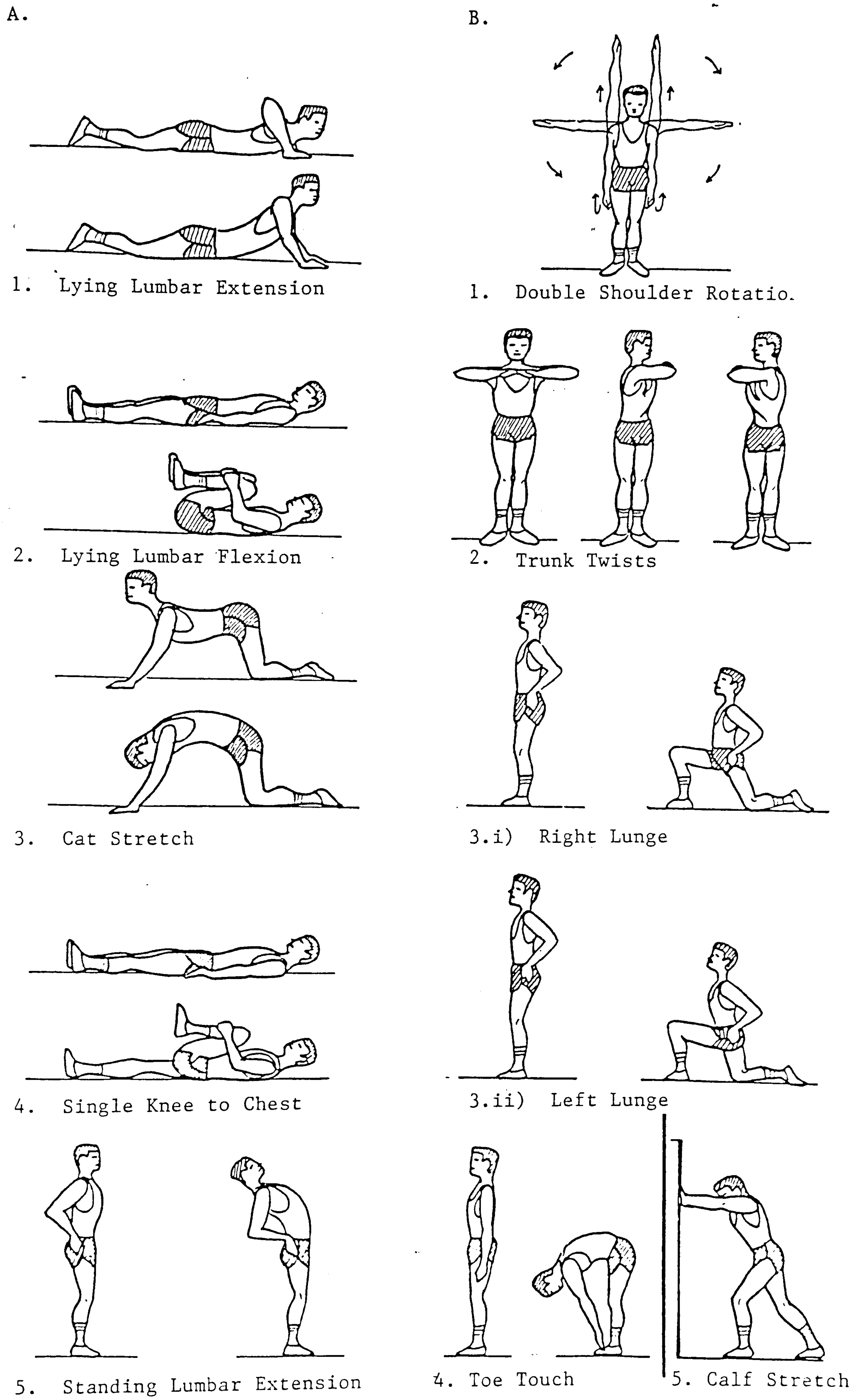


Figure 7. The McKenzie mobilisation (A) and conventional (B) exercises depicted in the order performed.

RESULTS

Differences between the sitting, mobilisation and conventional conditions (Table 21) were non-significant according to ANOVA ($p>0.05$). There were significant changes in stature during the sitting control period, the warm-up period, and the warm-down which differed from changes during the run ($p<0.05$). The mobilisation and conventional warm-downs offered no significant advantage over the sitting condition in unloading the spine ($p>0.05$).

Table 21. Mean (SD) change in stature (mm), during warm-up, running (12.5 km h-1) and warm-down exercises, following sitting, mobilisation and conventtional warm-up and warm-down procedures.

Exercise regimen:	Control	Warm-up	Running	Warm-down
Procedure:				
Sitting	0.67 (1.6)	0.30 (1.26)	-4.09 (1.83)*	1.58 (1.83)
Mobilisation	0.46 (1.5)	-1.15 (1.62)	-2.00 (1.07)*	1.33 (1.21)
Conventional	1.82 (3.1)	-0.97 (1.02)	-3.28 (1.46)*	1.12 (0.49)

(*$P<0.05$)

Two-way analysis of variance revealed that there was no interaction effect between the exercise regimen and the three procedures on spinal shrinkage ($p>0.05$). The choice of procedure prior to and after exercise had no effect on spinal shrinkage ($p>0.05$). There were significant differences in shrinkage during the four stages of the exercise regimen ($p<0.005$).

Tukey's Honestly Significant Difference Test (Daniel, 1987), showed that these differences were confined to changes in stature between the control condition and the 20 min run, the warm-up and the 20 min run, and the 20 min run and the warm down (Table 21).

Stature at the end of running was related significantly to stature at the end of warm-down in both experimental conditions. In other words the procedures did not affect the alterations in stature during the mobilisation and conventional warm-downs, $r=0.69$ and 0.98 respectively ($P<0.05$).

Flexibility, determine using a sit and reach test, was 30 (+103) mm and was inversely correlated with shrinkage in the control condition during the warm-up period ($r=-0.84$). Flexibility was also inversely related to shrinkage during running ($r=-0.77$) and recovery ($r=-0.80$) in the conventional condition ($P<0.05$).

The results from this section will be discussed in conjunction with section 7.2.

7.2 INTERVENTION STUDY 2: AN EVALUATION OF MOBILISATION PROCEDURES PRE- AND POST- CIRCUIT WEIGHT-TRAINING USING SPINAL SHRINKAGE.

INTRODUCTION

Spinal responses to CWT using a combination of free-weights, weight-training machines and unresisted truncal exercises (sit-ups and back extensions) have not previously been studied. The aim of this study was to examine the effectiveness of a modified McKenzie procedure (Figure 11; Section 7.1) in reducing spinal loading before circuit weight-training (CWT), and during recovery from exercise. It was hypothesised that the procedures would attenuate spinal loading when performed pre-CWT and reverse the effects of loading post-exercise. It was also hypothesised that a correlation would exist between physical, physiological and behavioural responses to loading.

METHODS

Eight healthy males, mean age 23.3 (4.4) years acted as subjects. As in the previous study all subjects were Sports Science undergraduates, habitually active in sport and athletics and had experience of using weight-lifting techniques. Subjects were requested to follow their normal routine on experimental days, avoiding strenuous activity.

The procedure of instruction in lifting technique and determination of the weight to be lifted used in section 5.7 was adopted for this study. The mobilisation procedure used the same exercises as and procedures as in Section 7.1 (Figure 7).

Two experimental and one control condition were used before and after CWT to determine the effects of mobilisation exercises on spinal shrinkage. Subjects were randomly assigned to either the control (sitting with the back supported in extension), pre-exercise mobilisation or post-exercise mobilisation conditions. This determined the activity performed during warm-up and warm-down periods. Stature was measured before and after a 10 min control period of sitting pre- exercise, after a 10 min warm-up, after CWT, after a 10 min warm-down, and after 10 min seated recovery.

Heart rate was measured throughout the protocol using short range radio telemetry (SPORT-TESTER PE3000). Ratings of perceived exertion (RPE) were monitored using Borg's (1970) scale. An eleven point pain scale with '0' representing no pain and '10' the worst pain imaginable, was used in rating low-back pain (LBP). Recordings were made during each exercise in the experimental conditions.

Changes in stature were measured as previously described (Section 6.1). Each subject underwent training on the stadiometer to ensure reliability of subsequent measurements. A standard deviation of less than 0.5 mm over 10 consecutive measures was used as criterion for adequate training. All subjects achieved the required level, obtaining an average of 0.40 (±0.09) mm in 2.1 (±1.1) training sessions, with 30 (±14) measures, taking 24.09 (±16.73) min. Flexibility was determined prior to testing using a sit and reach test. Back and leg strength were measured using a dynamometer (Takeikiki Kogyo).

Testing took place at 09:00 hours to control for circadian variation in stature (Tyrrell et al., 1985). Subjects were requested to follow their normal routine on experimental days, avoiding strenuous activity.

Changes in physiological variables between circuits were analysed using two-way ANOVA. Changes in perceptual responses were analyses using Friedman two-way ANOVA by ranks. Pearson's correlation and Spearman's Rank correlation analysis were used to determine the relationships between spinal shrinkage, the physiological and perceptual variables and time to complete the circuit. A probability level of 0.05 was set for statistical significance. All data analysis was performed using MINITAB Statistical Software.

RESULTS

The mean time taken to complete the circuits was 17.27 (1.54) min. Two-way ANOVA revealed there was no interaction effect between the exercise regimen and the three conditions on spinal shrinkage ($p>0.05$) (Table 22). The choice of procedure prior to and after exercise had no effect on spinal shrinkage ($p>0.05$). There were significant differences in shrinkage during the five stages of the exercise regimen ($p<0.005$). Tukey's Test (Daniel, 1987) showed that these differences were confined to changes in stature between the control condition and the CWT, the warm-up and CWT, and CWT and the warm down, and CWT and seated recovery. The warm-up and warm-down procedures, comprising mobilisation procedures, offered no advantage over the seated condition in unloading the spine ($p>0.05$).

Correlation analysis showed that spinal shrinkage was independent of RPE, LBP rating or time taken to complete the circuits. Spinal shrinkage during 10 min sitting in the warm-down condition was inversely correlated with flexibility ($r = -0.841$); this was not found for other conditions. Back strength was inversely related to shrinkage during the 10 min seated control period in the warm-down condition ($r=-0.707$) and to shrinkage during CWT ($r=0.662$), the greater shrinkage being attributable to higher loads used by the stronger subjects ($P<0.05$).

Table 22. The effect of a pre- and post-exercise mobilisation routine on change in stature during circuit weight-training

	Change in stature (mm)				
Exercise regimen:	Seated Control	Warm-up	CWT	Warm-down	Seated Recovery
Procedure:					
Seated Control	-0.10 (1.8)	-1.06 (2.15)	-2.53 (1.48)*	0.32 (1.18)	-0.33 (1.50)
Pre-mobilisation	0.41 (1.9)	0.32 (1.50)	-3.40 (1.35)*	0.75 (1.64)	-0.07 (0.65)
Post-mobilisation	0.41 (1.4)	0.26 (1.4)	-3.98 (1.28)*	1.68 (0.61)	0.15 (1.10)

(*P<0.05)

7.3 DISCUSSION OF INTERVENTION STUDIES

The aim of the intervention studies in Sections 7.1 and 7.2 were: to determine whether pre- and post-exercise mobilisation procedures reduced spinal loading during running and CWT; and whether a conventional warm-up routine or a mobilisation routine was better than sitting as a method of unloading the spine.

The results from study 1 showed that the changes occurring during a fixed period of spinal loading, a 20 min run were unaffected by the pre-exercise procedures employed. This finding indicated that neither the mobilisation or conventional warm-up exercises, were effective in attenuating spinal shrinkage caused by running. The mobilisation and conventional procedures caused a decrease in stature. These losses in stature were not significantly different from the gain in stature observed during the seated control condition suggesting that neither procedure offered any advantage over sitting pre-exercise.

Study 2 examined the effectiveness of the McKenzie mobilisation procedure in reducing spinal loading before and after a CWT session. Changes in stature during and after CWT were unaffected by the pre-and post-exercise mobilisations used. The pre-exercise mobilisation caused an increase in stature prior to CWT, but that this was not significantly different from that in the control and post-exercise mobilisation conditions. Similarly, the post-exercise mobilisation caused an increase in stature. Although this was a relatively large value, it was not significantly greater than for the control and pre-exercise mobilisation conditions. This supports the observations in Study 1.

These findings contrast with previous observations using gravity inversion prior to exercise (Boocock et al. 1988) during which appreciable unloading of the spine occurred as compressional forces were removed from the spine. In the procedures chosen in this study the spine was subjected to axial loading, flexion, extension and rotational movements all of which could cause compression of the intervertebral discs and result in shrinkage rather than unloading. This would reduce the effectiveness of the procedure as a method of unloading the spine. Other combinations of exercises incorporating less loading might be more effective. However, findings do not indicate that warm-up and warm-down procedures can be neglected as they may have beneficial effects on physiological responses that improve exercise performance.

Results suggest that spinal flexibility may have a role to play in attenuating the load on the spine during heavy physical activity. In Study 2, in the 10 min sitting during the warm-down the more flexible subjects showed less shrinkage than those less flexible. This supports the finding of Study 1, in which this relationship was apparent during the warm-up, during the run and post-exercise for the control trial.

If it could be shown that improvements in flexibility reduced spinal loading, flexibility training could be a beneficial adjunct to training programmes, by reducing the risk of back injury through excessive loading. Long term efforts to improve the flexibility of an athlete may be a useful means of reducing spinal loading during exercise. The mechanism by which flexibility attenuates shrinkage may be by reducing motion segment stiffness but this remains to be determined.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 EPIDEMIOLOGY SECTION

RUNNING SURVEY 1: INJURY PATTERNS AND TRAINING HABITS IN RECREATIONAL MARATHON RUNNERS

A retrospective survey of entrants in the 1986 Mersey Marathon showed that a high proportion of runners became injured, with most injuries (75%) occurring in training as opposed to racing. A significant number of injuries to marathon runners (12%) were to the lower back. The prevalence of low-back pain was 21%. These figures are similar to those previously reported in the literature. The majority of the training mileage undertaken by most runners was on the road and at a steady rate, but risk of injury was unrelated to this, and other extrinsic training variables.

The survey revealed that runners did not make the best use of warm-up or warm-down exercises. The amount of time spent on these activities by most runners was probably insufficient to have any physiological effect. It is recommended that better use be made of this aspect of training.

RUNNING SURVEY 2: A RETROSPECTIVE SURVEY OF INJURY PATTERNS AND TRAINING HABITS AMONG CROSS-COUNTRY RUNNERS

This study compared injury distribution and training characteristics of cross-country runners with those of marathon runners. The injury distribution was similar to that from the survey of Mersey Marathon runners. A greater proportion of cross-country running injuries was to the lower back (16%), a prevalence rate of 39%. These data suggest that the risk of lower back injury is less in marathon than cross-country running. Extrinsic training variables were unrelated to injury risk.

RUNNING SURVEY 3: A RETROSPECTIVE AND LONGITUDINAL SURVEY OF INJURY PATTERNS AND TRAINING HABITS IN CLUB MARATHON RUNNERS

This study employed both retrospective and longitudinal surveys to determine the incidence of low-back pain in club marathon runners. The possible association between extrinsic training variables and injury were also explored.

In the first part of the analysis, the retrospective survey showed the runners to be very similar in profile to the Mersey Marathon runners surveyed earlier (Section

5.1.1). The data revealed that 12% of all injuries were to the lower back which supports the finding of Section 5.1.1. The prevalence of lower back injury was 27%. Extrinsic training variables were cited as the cause of 68% of all injuries. These variables, which are under the runners control, were not significantly correlated with injury risk. The attitude to warm-up and warm-down regimens was better than for the earlier study of marathon runners, but was not associated with a decrease injury risk.

In the second part of the survey, a longitudinal study of training diaries kept by the runners over a 40 week period, showed that 10% of injuries were to the lower back. The incidence of lower back injury was 37% over this period. This incidence of injury was not significantly associated with any of the extrinsic training variables under investigation.

WEIGHT-TRAINING SURVEY: A SURVEY OF INJURIES AND ATTITUDES TOWARDS TRAINING IN WEIGHT-TRAINERS

A retrospective questionnaire was designed to inform on training habits, injuries and attitudes towards training and injury in weight-trainers. An aim of the study was to determine the rates of injuries in weight-training populations. This was hampered by the reluctance of commercial gymnasiums to allow access to clients, thereby reducing the sample size. A possible reason for this may have been fear of the establishments' managers that lack of supervision of trainers and unqualified staff may have been highlighted.

Recruitment of subjects for this survey proved difficult. Thirty weight-trainers were recruited to the survey and the overall injury rate for the weight-trainers was 73% over 12 months, a similar level to that found among the runners. Seventeen percent of all injuries were to the lower back, the prevalence of low-back pain being survey was 13%. This is lower than that found in runners (21-39%). Weight-trainers like their counterparts from the surveys of runners, probably under-used the warm-up and warm-down as part of training.

The surveys of running populations identified a high prevalence (21-39%) and incidence (37%) of low-back pain. The amount of time spent on warm-up and warm-down activities reflected the low rating of importance attached to these activities by the runners. Analysis of survey data failed to show a relationship between extrinsic training variables and low-back pain. It is suggested that experimental and survey work concentrate on intrinsic factors such as anthropometric, physiological and biomechanical and extrinsic training variables in predisposition towards lower back injury in running and CWT.

8.2 EXPERIMENTAL SECTION

EXPERIMENT 1: RUNNING SPEED AND SPINAL SHRINKAGE IN RUNNERS WITH AND WITHOUT LOW-BACK PAIN

This experiment tested three hypotheses: runners with low-back pain show greater change in stature to a given running regimen than asymptomatic counter-parts; spinal shrinkage increases with an increase in running speed; spinal shrinkage is reduced with age. No difference in response to running was observed between the two groups. Spinal shrinkage was shown to increase with the speed of running, presumably because of the higher ground reaction forces transmitted to the lower back, and to be greater in the early part of a run. Spinal shrinkage was independent of age within the range examined.

The absence of a difference in spinal shrinkage due to low-back pain symptoms may be explained by the low level of pain experienced by the runners. Runners with more severe pain have not been studied. Additional investigation is needed to ascertain whether spinal shrinkage could discriminate between runners with more severe low-back pain symptoms and asymptomatic individuals. Data did not allow extrapolation to shrinkage over the marathon distance. More data points than the three collected in the study would be required in order for a power function prediction to be made. Alternatively, spinal shrinkage could be measured after a run over the marathon distance. This was attempted in Section 6.3.

EXPERIMENT 2: DIURNAL VARIATION IN STATURE IN SUBJECTS WITH SEVERE CHRONIC LOW-BACK PAIN.

The previous study failed to show differences in spinal shrinkage in response to running between runners with and without low-back pain. It was hypothesised that subjects on an orthopaedic ward awaiting surgery for chronic low-back pain would show increased diurnal variation in stature compared with previously reported values. Difficulty arose in training subjects on the stadiometer, which could be a potential limitation of this type of stature measurement. It was not possible, for ethical reasons to control subjects' activities during the day.

Diurnal variation in stature, in patients with severe chronic low-back pain was only 40% of the normal range. This may have been due in part, to behaviourial characteristics of the patients which, for ethical reasons, could not be controlled. It is recommended that data be obtained from a population with low-back pain symptoms between the extreme examples in this study and the previous study (Section 6.1).

EXPERIMENT 3: THE EFFECT OF A LONG DISTANCE RUN ON SPINAL SHRINKAGE

Section 6.1 showed that stature was lost in the early stages of running, signifying a deterioration in the shock absorbing properties of the spine as the rate of shrinkage changes with time. It was not possible to extrapolate from these data to a run of longer duration. This study examined the amount of spinal shrinkage in a treadmill run at marathon race pace. Neuromuscular function was assessed using EMG and changes in stride rate during the run. The relationships between heart rate, rectal temperature, cadence variations, perception of effort and ratings of low-back pain were investigated.

Stature data measured post-exercise were unreliable because of large measurement errors post-exercise. This was due to the inability of runners to maintain the correct posture on the stadiometer, caused by orthostatic responses experienced after the run. The change in stature after the treadmill run was 3.93 ($\pm$1.85) mm.

The runners all stopped running due to exhaustion prior to the expected ttime, based on their marathon performance. No significant change in stride rate or EMG activity of the back and leg muscles, was observed between the fifth minute and the last minute of running. This showed that the cessation of exercise was not due to neuromotor fatigue. Loss of body mass through dehydration, and a significantly elevated heart rate implied that dehydration and heat stress caused the cessation of running.

It is recommended that further work should examine the effects of marathon running on muscle fatigue in field conditions. In this way the cessation of exercise due to circulatory stress or lack of motivation, induced by the laboratory environment, may be avoided. Also, it may be necessary to find an alternative method of measuring changes in stature whilst subjects are experiencing orthostatic stress, perhaps by taking measures in the seated or recumbent position.

EXPERIMENT 4: PHYSIOLOGICAL AND SPINAL RESPONSES TO CIRCUIT WEIGHT-TRAINING (CWT)

Circuit weight-training (CWT) used as a method of aerobic training may cause an excessive degree of spinal loading in addition to loading the oxygen transport system. Two studies examined the intensity of exercise involved in circuit weight-training (CWT). The first study determined the physiological and perceptual responses to CWT over three circuits. The second study examined the physical responses to CWT using spinal shrinkage as an index of spinal loading.

It was found that:

1) Physiological strain increased with the duration of the CWT but overall this regimen may not provide an adequate aerobic training stimulus. The oxygen consumption of the subjects was only 50% of maximum showing that the aerobic systems were only taxed to a moderate level.
2) Blood lactate levels were relatively high (6.9 mM), showing the exercise to include a high anaerobic component, and was correlated with time to complete the circuit.
3) Spinal shrinkage was unrelated to the physiological strain and perceptual responses in CWT.

It is recommended that the length of CWT be chosen to ensure that the target intensity levels are maintained for 15 min which would require the extension of the circuit used in this study by approximately 5 min. Additionally CWT should include more exercises involving large muscle masses than in the present study. The use of 40% 1 RM to determine loading for arm exercises may be inappropriate as it may increase the reliance of smaller muscle groups on anaerobic metabolism.

The CWT used in this study differed from previously reported regimens in that it did not use exercises deliberately chosen to load the spine. The inclusion of such exercises in a circuit may have a role in the reduction of spinal shrinkage. The shrinkage observed (2.5 mm) was less than for running for 15-20 min (about 3 mm). This type of circuit is recommended as it does not appear to overload the spine. However, the physiological data indicated CWT would have little value as a stimulus for aerobic training unless used in combination with other modes of aerobic exercise. Circuit weight-training should be carefully designed to tax the aerobic rather than anaerobic systems and that exercises which do not load the spine directly be incorporated.

8.3 INTERVENTION SECTION

The epidemiological investigations indicated that warm-up and warm-down procedures were not highly utilised by runners and weight-trainers. The possible protective effects of warm-up and warm-down exercises advocated to reduce the risk of back injury, were investigated using spinal shrinkage to determine whether spinal loading could be attenuated or reduced. A series of spinal mobility exercises, the McKenzie procedure was adapted for possible use by athletes as a pre- or post-exercise routine.

INTERVENTION STUDY 1: AN EVALUATION OF WARM-UP AND WARM-DOWN, PROCEDURES BEFORE AND AFTER RUNNING, USING SPINAL SHRINKAGE

This study compared a modified McKenzie mobilisation procedure with a conventional warm-up procedure, to determine the effect on change in stature after a 20 min run. The relationship between spinal shrinkage and flexibility was examined.

The procedures did not significantly affect the alterations in stature pre- or post-exercise, though more direct methods of unloading (gravity inversion) have demonstrated a short-lived effect. Spinal flexibility was negatively related to shrinkage in the control condition during the warm-up period and to shrinkage during running and recovery in the conventional condition. The protective role of flexibility in spinal shrinkage requires further study. It is recommended that better use of warm-up and warm-down time to develop flexibility, in training, may have a protective function by reducing response to spinal loading.

INTERVENTION STUDY 2: AN EVALUATION OF MOBILISATION PROCEDURES PRE- AND POST-CIRCUIT WEIGHT-TRAINING USING SPINAL SHRINKAGE.

Increased vulnerability of the spine to damage could be a consequence of loading induced by CWT. This study examined the effectiveness of a modified McKenzie procedure in reducing spinal loading before, and during recovery from, circuit weight-training (CWT). It was hypothesised that spinal shrinkage would be reduced using the pre-exercise procedures and reversed by post-exercise procedures.

Changes in stature during CWT were unaffected by the pre- and post-exercise mobilisations used, which supports previous observations on running. In sitting during the warm-down the more flexible subjects showed less shrinkage than the less flexible subjects. This supports the findings of the previous study that spinal flexibility may have a role to play in attenuating the load on the spine during physical activity. The role of flexibility in attenuating shrinkage needs further study. Long term improvements in the flexibility of an athlete may be a more profitable means of reducing spinal loading during exercise, than short term mobilisation procedures.

8.4 OVERALL CONCLUSION

This thesis has demonstrated that the prevalence of low-back injury in runners is high enough to warrant further attention. Although runners attributed the majority of injuries to training variables, epidemiological data collected did not allow the ascription of causal training faults to particular injuries, including low-back pain. Training variables, such as high running mileage or abrupt changes in mileage, should be experimentally controlled in runners training schedules, to determine their effects on low-back pain in running.

Further information is required to determine the rate of low-back injury in CWT. The low prevalence rate obtained in this study probably reflects the small sample surveyed. Epidemiological data need to be collected, longitudinally, on a large sample of weight-trainers to determine the true incidence of low-back injury.

Measures of spinal shrinkage were not sensitive enough to

pain sufferers and asymptomatic individuals, or between subjects of different ages. This finding is in apparent contradictions of finding from cadaver studies, which have demonstrated that greater creep occurs in degenerated and older spines. The probable reasons for the discrepancy are:- the selection of subjects with mild symptoms whose training was unaffected, rather than with moderate symptoms which affected training; and the low numbers of subjects from each age group. Further investigation is required to determine the usefulness of shrinkage as a diagnostic measure for low-back pain sufferers.

Shrinkage caused by running was shown to increase with the speed and duration of a run. Insufficient data were collected to predict shrinkage caused by a marathon race. Also, methodological difficulties prevented this from being measured directly. It is likely that shrinkage over the marathon distance is greater than for shorter runs, but the magnitude of shrinkage remains to be predicted or measured. Fatigue caused by glycogen depletion in a marathon run may affect the ability of the leg muscles to attenuate the shock loading, which may in turn increase spinal laoding. These changes in leg muscle function can be detected using EMG and should be related to spinal responses to loading before and after the onset of fatigue.

Whilst there was little difference in spinal shrinkage between running and CWT, the physiological responses indicated running to be the preferable from of aerobic training. The physiological load imposed by CWT limits its usefulness as an aerobic training stimulus. Careful selection of exercises and loading would be required in order to ensure an aerobic training effect. This study has shown that selection of exercises which do not load the spine directly may reduce spinal loading in CWT.

The intervention studies demonstrated that conventional warm-up and warm-down exercises and mobilisation exercise do not reduce or reverse spinal loading induced by running or CWT. There was some evidence to suggest that spinal loading in exercise may be reduce in more flexible subjects. The role of flexibility in attenuating spinal loading warrants further attention.

REFERENCES

Adams, M.A. and Hutton.W.C. (1980) The effects of posture on the role of the apophyseal joints in resisting intervertebral compressive forces. Journal of Bone and Joint Surgery 62-B, 358-362.

Adams, M.A. and Hutton.W.C. (1982) Prolapsed intervertebral disc: a hyperflexion injury of the spine. Spine 6, 184-191.

Adams, M.A. and Hutton.W.C. (1983) The effect of posture on the fluid content of the lumbar intervertebral discs. Spine 7, 665-671.

Adams, M.A., Dolan, P. and Hutton.W.C. (1987) Diurnal variations in the stresses on the lumbar spine. Spine 12, 130-137.

Adams, M.A. Dolan, P., Hutton, W.P. and Porter, R.W. (1990) Diurnal changes in spinal mechanics and their significance. Journal of Bone and Joint Surgery 72-B, 266-270.

Adams, M.A., Hutton.W.C. and Stott, J.R.R. (1980) The resistance to flexion of the lumbar intervertebral joint. Spine 5, 245-253.

Alexander, M.J.L. (1985) Biomechanical aspects of lumber spine injuries in athletes: a review. Canadian Journal of Applied Sports Science 10, 1-20.

Allen, T.E., Byrd, R.J. and Smith, D.P. (1976) Haemodynamic consequences of circuit weight-training. Research Quarterly 47, 299-306.

Althof, I., Brinckmann, P., Frobin, W., Sandover, J. and Burton, A.K. (1992) Improved method of stature measurement using quantitative determination of spinal loading: Applications to sitting postures and whole body vibration. Spine (in Press).

American College of Sports Medicine (1978) The recommended quantity and quality of exercise for developing and maintaining of fitness in healthy adults, Medicine and Science in Sports and Exercise 10, V11-X.

Amin, A.A., Corlett, E.N. and Bonney, R.A. (1988) Does wearing a seat belt alter the load on the back whilst driving. In: Contemporary Ergonomics. (Edited by E.D. Megaw). London, Taylor Francis, pp 538-543.

Andersson, B.J.G., Ortengren, R. and Herberts, P. (1977) Quantitative electromyographic studies of back muscle activity related to posture and loading. Orthopaedic Clinics of North America 8: 85-96.

Asmussen, E. (1973) Growth in muscular strength and power. In: Physical Activity, Human Growth and Development. (Edited by G.L. Garick). Academic Press, New York.

Astrand, P.O. and Rodahl, K. (1986) Textbook of Work Physiology McGraw-Hill, New York.

Ballor, D.L., Beque, D.M. and Katch, V.L. (1987) Metabolic responses during hydraulic resistance exercise, Medicine and Science in Sports and Exercise 19, 363-367.

Basford, J.R. (1986) Weight-lifting weight-training and Injuries, Orthopaedics 8, 1051-1056.

Basmajian, J.V. and Deluca, C.J. (1985) Muscles Alive (5th Ed). Williams and Wilkins, Baltimore.

Bendix, A., Jensen, C.V. and Bendix, T. (1988) Posture, acceptability and energy consumption on a tiltable and knee-support chair. Clinical Biomechanics 3, 66-73.

Biering-Sorensen, F. (1982) Low back trouble in a population of 30-,40-, 50-, and 60 year old men and women. Danish Medical Bulletin 29, 289-298.

Biering-Sorensen, F. (1983) A prospective study of low-back pain in a general population. 1. Occurrence, recurrence and aetiology. Scandinavian Journal of Rehabilitation Medicine 15, 71-79.

Billings, R.A., Burry, H.C. and Jones, R. (1977) Low back injury in sport. Rheumatology and Rehabilitation 16: 236-240.

Blair, S.N., Kohl, H.W. and Goodyear, N.N. (1987) Rates and risks for running and exercise injuries; studies in three populations. Research Quarterly 58: 221-228.

Boocock, M.G., Reilly, T., Linge, K. and Troup, J.D.G. (1986) Fine measurement of stature for measuring spinal loading. In: Kinanthropometry III. (Edited by T.Reilly, J.Watkins and J.Borms), E. and F.N.Spon, London, pp 98-103.

Boocock, M.G., Garbutt, G., Reilly, T., Linge, K. and Troup, J.D.G. (1988) The effect of gravity inversion on exercise-induced spinal loading. Ergonomics 31: 1631-1637.

Boocock, M.G., Garbutt, G., Linge, K., Reilly, T. and Troup. J.D.G. (1990) Changes in stature following drop jumping and post-exercise gravity inversion. Medicine and Science in Sports and Exercise 22: 385-390.

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

Borg, G.A.V. (1982) Psychophysical bases of perceived exertion. Medicine and Science in Sports and Exercise 14, 377-381.

Bourne, N.D. and Reilly, T. (1991) Effect of a weight-lifting belt on spinal shrinkage. British Journal of Sports Medicine 25, 209-212.

Brady, T.A., Cahill. B.R. and Bodnar, L.M. (1982) Weight-training related injuries in the high-school athlete. American Journal of Sports Medicine 10: 1-5.

Brinckmann, P. (1988) Stress and strain of human lumbar discs. Clinical Biomechanics 3: 232-235.

Brinckmann, P., Frobin, W., Hierholzer, E. and Horst, M. (1981) Deformation of the vertebral end-plate under axial loading. Spine 8: 851-856.

Brody, D.M. (1980) Running injuries. CIBA Clinical Symposium, 32: 1-36.

Brooks, G.A. (1985) An aerobic threshold: a review of the concept and direction for the future, Medicine and Science in Sports and Exercise 17: 22-31.

Brooks, G.A. and Fahey, T.D. (1984) Exercise Physiology: Human Bioenergetics and its Applications MacMillan, New York.

Browne, T.D., Yost, R.P and McCarron, R.F. (1970) Lumbar ring apophyseal fracture in an adolescent weight-lifter: a case report, American Journal of Sports Medicine 18: 533-535.

Brunet, M.E., Cook, S.D., Brucker, M.R. and Dickinson, J.A. (1990) A survey of injuries in 1505 competitive and recreational runners. Journal of Sports Medicine and Physical Fitness 30, 307-315.

Burton. A.K. and Tillotson, K.M. (1991) Measurements of spinal strain to estimate loads on the spine during overhead working postures. Health and Safety Executive Report HSE Contract number 1/LMD/126/373/89.

Cabri, J.M.H. (1989) The influence of different doses of alprazolam on muscle activity, In: Function and cardiovascular response to concentric and eccentric efforts in isokinetic movement conditions. Doctoral Thesis. Vrije Universiteit Brussel, Brussels.

Cannon, S.R. and James, S.E. (1984) Back pain in athletes. British Journal of Sports Medicine 18: 159-164.

Cantu, R.C. (1986) Low back pain in athletes. In: Sports injuries: the unthwarted epidemic. (Edited by P.F. Voenger and E.F. Hoerner), PGS Publishing Co., U.S.A.

Cavanagh, P.R. and Lafortune, M.A. (1980) Ground reaction forces in distance running. Journal of Biomechanics 13, 397-406.

Chaffin, D.B., Herrin, G.D. and Keyserling, W.M. (1978). Pre-employment strength testing - an updated position. J. Occupational Medicine, 20, 403-408.

Clement, D.B., Taunton, J.E., Smart, W.G. and McNicol, K.L. (1981) A survey of overuse running injuries. Physician and Sportsmedicine, 9, 47-58.

Corlett, E.N. and Bishop, P. (1976) A technique for assessing postural discomfort, Ergonomics 19: 175-193.

Corlett, E.N., Eklund, J.A.E., Reilly, T. and Troup. J.D.G. (1987) Assessment of workloads from measurements of stature. Applied Ergonomics 18: 65-71.

Dainty, D.A. and Norman, R.W. (1987) Standardising Biomechanical Testing in Sport Human Kinetics, Champaign, Il., U.S.A.

Daniel, W.W. (1987) Biostatistics: A Foundation for Analysis in the Health Sciences Wiley, New York.

Davies, C.T.M. and Thompson, M.W. (1979) Aerobic performance of female marathon and male ultra-marathon athletes. European Journal of Applied Physiology 41: 233-245.

Davies, J.E. (1980) The spine in sport-injuries, prevention and treatment. British Journal of Sports Medicine 14: 18-20.

De Puky, P. (1935) The physiological oscillation of the length of the body. Acta Orthopaedica Scandinavica 6: 338-347.

Devereaux, M.D. and Lachmann, S.M. (1980) Athletes attending a sports injuries clinic - a review. British Journal of Sports Medicine 17: 137-142.

Edwards, R.H.T. (1981) Human muscle fatigue. In: Human muscle fatigue: physiological mechanisms (Edited by R.Porter and J. Whelan) Pitman Medical, London.

Edwards, R.H.T., Hill, D.K. and McDonnell, M.J. (1972) Myothermal and intramuscular pressure measurement in man. Journal of Physiology 224: 58P.

Eklund, J.A.E. and Corlett, E.N. (1984). Shrinkage as a measure of the effect of loading on the spine. Spine 9: 189-194.

Eklund, J.A.E and Corlett, E.N. (1987) Evaluation of spinal loads and chair design in seated work tasks. Clinical Biomechanics 2: 27-33.

Ericson, M.O. and Goldie, I. (1989) Spinal shrinkage with three different types of chair whilst performing visual display unit work. International Journal of Industrial Ergonomics 3: 177-183.

Fitzgerald, J.G. (1972) Changes in spinal stature following brief periods of static shoulder loading. Institute of Aviation Medicine Report No. 514.

Floyd, W.F. and Silver, P.H.S. (1955) The functions of the erector spinae muscles in certain movements and postures in man. Journal of Physiology 129, 184-203.

Foreman, T.K. (1989) Back pain prevalence, work activity analysis and spinal shrinkage. Doctoral thesis. University of Liverpool.

Foreman, T.K. and Troup, J.D.G. (1987) Diurnal variations in spinal loading and the effects on stature: a preliminary study of nursing activities. Clinical Biomechanics 2: 48-54.

Fowler, N., Lees, A. and Reilly. T. (1991) Spinal shrinkage during loaded and unloaded drop-jumping (Abstract). Journal of Sports Sciences 9, 336-337.

Frymoyer, J.W., Pope, M.H., Constanza, M.C., Rosen, J.C., Goggin, J.E. and Wilder, D.G. (1980) Epidemiologic studies of low-back pain. Spine, 5, 419-423.

Gettman, L.R. (1978) Aerobic cost of isokinetic slow and fast speed training programmes (abstract) AAHPER Research Papers p 71.

Gettman, L.R. and Ayres, J.J. (1978), Aerobic changes through 10 weeks of slow and fast speed isokinetic training (Abstract), Medicine and Science in Sports and Exercise 10: 47.

Gettman, L.R., Ayres, J.J., Pollock. M.L. and Jackson. A (1978) The effect of circuit weight-training on strength, cardiorespiratory function and body composition of adult men. Medicine and Science in Sports and Exercise 10: 171-176.

Gettman, L.R. and Pollock. M.L (1981) Circuit weight-training: a critical review of its physiological benefits, Physician and Sportsmedicine 9: 44-60.

Gettman, L.R., Culter, L.A. and Stratham, T. (1980) Physiologic changes after 20 weeks of isotonic vs isokinetic circuit training, Journal of Sports Medicine and Physical Fitness 20: 265-274.

Gollhofer, A. and Komi, P. (1987) Measurement of man-shoe-surface interaction during locomotion, Medicine and Sport Science 26: 187-199 (Karger, Basel).

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

Guten, G. (1981) Herniated lumbar disc associated with running: a review of 10 cases. American Journal of Sports Medicine 9, 155-159.

Hempel, L.S. and Wells. C.L. (1985) Cardiorespiratory cost of the Nautilus express circuit. Physician and Sports Medicine 13, 82-97.

Hindle. R.J., Murray-Leslie, C. and Atha, J. (1987) Diurnal stature variation in ankylosing spondylitis. Clinical Biomechanics 2: 152-157.

Hoeberigs, J.H. (1992) Factors related to the incidence of running injuries: a review. Sports Medicine 13, 408-422.

Holdsworth, F. (1970) Fractures, dislocations and fracture dislocations of the spine. Journal of Bone and Joint Surgery 52A, 1534-1551.

Jacobs, I. (1986) Blood lactate: implications for training and sports performance. Sports Medicine 3, 10-25.

James S.L. Bates, B.T. and Osternig, L.R. (1978) Injuries to runners. American Journal of Sports Medicine 6, 40-50.

Jayshinghe, W.J., Harding, R.H., Anderson, J.A.D. and Sweetman, B.J. (1978) An electromyographic investigation of postural fatigue in low back pain - a preliminary study. Electromyography and Clinical Neurophysiology 18, 191-198.

Kaigle, A.M, Magnusson, M., Pope, M.A., Browman, H. and Hansson, T. (1992) In vivo measurement of intervertebral disc creep: a preliminary report. Clinical Biomechanics 7, 59-62.

Kapandji, I.A. (1974) The physiology of the joints, 3: the trunk and the vertebral column. Edinburgh, Churchill-Livingstone.

Karlsson, J., Sjodin, B., Jacobs, I. and Kaiser, P. (1981). Relevance of muscle fibre type to fatigue in short intense and prolonged exercise in man. In: Human muscle fatigue physiological mechanisms. (Edited by R. Porter and J. Whelan.) Pitman Medical, London.

Kazarian, L.E. (1972) Dynamic response characteristics of the human spinal column. Acta Orthopaedica Scandinavica 146 (Suppl), 1-86.

Kazarian, L.E. (1975) Creep characteristics of the human spinal column. Orthopaedic Clinics of North America, 6,3-18.

Kersely, G.D. (1979) Back pain: its problems and treatments. Current Medical Research and Opinion, 6, Suppl. 2, 27-32.

Keyserling, W.M., Herrin, G.D. and Chaffin, D.B. (1980) Isometric strength testing as a means of controlling medical incidents on strenuous jobs. Journal of Occupational Medicine 22, 332-336.

Klingenstierna, U. and Pope, M. (1987) Body height changes from vibration. Spine, 12: 566-568.

Kilbom, A., Gamberale, F., Persson, J. and Annwall, G. (1983) Physiological and psychological indices of fatigue during static contractions, European Journal of Applied Physiology, 50: 1799-193.

Koeller, W., Funke, F. and Hartmann, F. (1984) Biomechanical behaviour of the human intervertebral discs subjected to long lasting axial loading. Biorheology 21, 675-687.

Komi, P. (1984) Fatigue and recovery in neuromuscular function. Medicine and Sports Science 17: 187-201 (Karger, Basel).

Komi, P.V. (1992) Stretch-shortening cycle. In: Strength and Power in Sport, (Edited by P.V. Komi). Oxford, Blackwell Scientific Publications.

Komi, P., Hyvarinen, T., Gollhofer, A. and Mero, A. (1986) Man-shoe-surface interaction: special problems during marathon running. Acta University Oulua A 179: 69-72.

Koplan, J.P. Powell, K.E., Sikes, R.K., Shirley, R.W. and Campbell, C.C. (1982) An epidemiological study of the benefits and risks of running. Journal of the American Medical Association 248: 3118-3121.

Krag, M.H., Cohen, M.D., Haugh, L.D and Pope, M.H. (1990) Body height changes during upright and recumbent postures. Spine 15, 202-207.

Kumar, S. (1991) Cumulative load as a risk factor for back pain. Spine 15, 1311-1316.

Lagasse, P (1987) Neuromuscular considerations, Ch 4. In: Standardising Biomechanical Testing in Sport (Edited by D.A.Dainty, and R.W.Norman) Human Kinetics, Champaign, Il., U.S.A.

Leatt, P., Reilly, T. and Troup, J.D.G. (1985) Unloading the spine. In: Contemporary Ergonomics, (Edited by D. Obourne). London, Taylor Francis.

Leatt, P., Reilly, T. and Troup. J.D.G. (1986) Spinal loading during circuit weight-training and running. British Journal of Sports Medicine 20, 119-124.

Lees, A (1988) The role of athlete response tests in the biomechanical evaluation of running shoes. Ergonomics 31, 1673-1682.

Lutter, L. (1980) Injuries in the runner and jogger. Minnisota Medicine 63, 45-51.

Lysholm, J. and Wiklander, J. (1987) Injuries to runners. American Journal of Sports Medicine 15, 168-171.

Lysens, R., Steverlynck, A., van der Auweele. Y., Rensen, L., Classens, A., and Ostyn, M. (1984) The predictability of sports injuries. Sports Medicine 1, 6-10.

Macleod, D., Maughan, R., Nimmo, M. Reilly, T and Williams, C. (1987) Exercise: benefits, limits and adaptations E. and F. Spon, New York.

McArdle, W.D. and Foglia, G.F. (1969) Energy cost and respiratory stress of isometric and weight-training exercise, Journal of Sports Medicine 9, 23-30.

McArdle,W.D., Katch.F., and Katch.V.L. (1991). Exercise physiology: energy, nutrition and human performance. Lea and Febiger, Philadephia.

McClay, I.S., Lake, M.J. and Cavanagh, P.R. (1990) Muscle activity during running, In: Biomechanics of distance running, (Edited by P.R. Cavanagh). Human Kinetics, Champaign, U.S.A.

McGill, S.M and Brown, S. (1992) Creep response of the lumbar spine in prolonged full flexion. Clinical Biomechanics 7, 43-46.

McMahon, T.A., Valiant, G. and Frederick, E.C. (1987) Groucho Running. Journal of Applied Physiology 62, 2326-2337.

McKenzie, R. (1980) Treat your own back, Spinal Publications, New Zealand.

Magnusson, M., Hult., E., Lindstrom, I., Lindell, V., Pope, M. and Hansson, T. (1990) Measurement of time-dependent height loss during sitting. Clinical Biomechanics 5, 137-142.

Marcinik. E.J., Hodgdon. J.A. and O'Brien. J.J (1987) A comparison of the sprain and strain injury rates during aerobic/calisthenic and aerobic/circuit weight-training programs. Military Medicine 152, 252-252.

Maughan, R.J. and Leiper, J.B. (1983) Aerobic capacity and fractional utilisation of aerobic capacity in elite and non-elite male and female marathon runners. European Journal of Applied Physiology 52, 80-87.

Maughan, R.J. and Miller, J.D.B. (1983) Incidence of training-related injuries among marathon runners. British Journal of Sports Medicine 17, 162-165.

Miller, D.I. (1990) Ground reaction forces in distance running. In Biomechanics of Distance Running (Edited by P.R. Cavanagh), Human Kinetics, U.S.A.

Milvy, P. (1977) The Marathon: Physiological, Medical, Epidemiological and Psychological Studies. Annals of the New York Academy of Science, New York.

Munro, C.F., Miller, P. and Fitzgerald, A.J. (1987) Ground reaction forces in running: a reexamination. Journal of Biomechanics 20, 147-155.

Nachemson, A. (1965) The effect of leaning on intradiscal pressure. Acta Orthopaedica Scandinavica 35, 314-318.

Nachemson, A. and Elfstrom, G. (1970) Intravital disc pressure measurements in lumbar discs. Scandinavian Journal of Rehabilitation Medicine, Suppl 1, 1-40.

NASA. (1978) Anthropometric source book. Volume 1: Anthropometry for designers: NASA Reference Publication No. 1024.

Newsholme,E.A. (1986) Application of principles of metabolic control to the problem of metabolic limitations in sprinting, middle distance running, and marathon running. In: Human Muscle Power. (Edited by Jones, N.L., McCartney, N. and McComas, A.J.) Human Kinetics, Champaign, U.S.A).

Newsholme, E.A. (1987) Application of metabolic logic to the questions of causes of fatigue in marathon races. In: Exercise: Benefits, Limits and Adaptations. (Edited by Macleod, D., Maughan, R., Nimmo, M., Reilly,T. and Williams, C.) E and F. Spon, London.

Newsholme, E.A. and Leech, A.R. (1983) Biochemistry for the Medical Sciences. John Wiley, London.

Nicol, C., Komi, P.V. and Marconnet, P. (1991) Combined effects of marathon race on running kinematics and neuromuscular function (Abstract). In: XIIIth International Congress on Biomechanics Book of Abstracts, University of Western Australia, Perth.

Norman, R.W. and Komi, P.V. (1979) Electromechanical delay in skeltal muscle under normal movement conditions. Acta Physiologica Scandinavica, 106, 241.

Oliver, J. and Middleditch, A. (1991) Functional anatomy of the Spine, Butterworth-Heinemann, Oxford.

Ovara, S. and Puranen, J. (1978) Athletes exertion injuries. Annales Chiruriqiae et Gynacologiae 67: 58-65.

Pagliano, J. and Jackson, D. (1980) The ultimate study of running injuries. Runner's World Nov, 42-50.

Passmore, R. and Durnin, J.V.G.A.(1955) Human energy expenditure, Physiological Reviews 9: 23-30.

Perey,O. (1957) Fracture of the vertebral end-plate in the lumbar spine: and experimental biomechanical investigation. Acta Orthopaedica Scandinavica (Suppl. 25).

Pheasant, S.T. (1991) Ergonomics, Work and Health. MacMillan Press, London.

Pollock, M.L., Cureton, T.K. and Greneiger, L. (1969) Effects of frequency of training on working capacity, cardiovascular function, and body composition of adult men. Medicine and Science in Sports and Exercise 1, 70-74.

Pollock. M.L., Tiffany, J. and Gettman, L.R. (1970) Effects of frequency of training on serum lipids, cardiovascular function and body composition. In: Exercise and fitness - 1969 (Edited by D.B. Franks) Athletic Institute, New York,

Pollock, M.L. (1973) The quantification of endurance training programmes. In :Exercise and sports science reviews,(Edited by J. Wilmore) Academic Press, New York.

Poussaint, A.F. (1980) Psychological and psychiatric factors in the low back pain patient. In: Symposium on idiopathic low back pain (Edited by: A.A. White and S.L. Gordon) C.V.Mosby, Miami.

Pollock, M.L., Gettman, L.A. Milesis, C.A., Bah, M.D., Durstine, L. and Johnson, R.B. (1977) Effects and frequency of duration of training on attrition and incidence of injury. Medicine and Science in Sports and Exercise 9, 31-36.

Powell, K.E., Kohl, H.W., Casperson, C.J. and Blair, S.N. (1986) An epidemiological perspective on the causes of running injuries. Physician and Sportsmedicine 14: 101-114.

Reilly, T. (1975) An ergonomic evaluation of occupational stress in professional football. PhD Thesis, Liverpool Polytechnic.

Reilly, T. (1990) Circadian rhythms and physical activity, Critical Reviews in Bioengineering 18: 165-180.

Reilly, T. and Foreman, T.K. (1984) Recreation marathon running: some observations and correlates of performance. In: Coombes, K. (Ed). Proceedings of the Ergonomics Society Conference (Taylor and Francis, London).

Reilly, T. and Pedan, F. (1989) Investigation of external loading in females. Journal of Human Movement Studies 17: 165-172.

Reilly, T. and Seaton, A. (1990) Physiological stain unique to field hockey, Journal of Sports Medicine and Physical Fitness 30, 142-

Reilly, T. Tyrrell, A. and Troup, J.D.G. (1984) Circadian variation in human stature. Chronobiology International 1, 121-126.

Reilly, T., Grant, R., Linge, K and Troup, J.D.G. (1988) Spinal shrinkage during treadmill running. In: Proceedings of the Olympic Science Congress. SOSOC, Seoul.

Rovere, G.D. (1987) Low back pain in athletes. Physician and Sportsmedicine 15, 105-117.

Roaf, R. (1960) A study of the mechanics of spine injuries. Journal of Bone and Joint Surgery 42-B, 810-823.

Saltin, B. (1981) Muscle fibre recruitment and metabolism in prolonged exhaustive dynamic exercise. In: Human Muscle Fatigue Physiological Mechanisms (Edited by R. Porter and J. Whelan) Pitman Medical, London.

Sheehan, G.A. (1977) An overview of overuse syndromes in distance runners. In: The Marathon: Physiological, Medical, Epidemiological and Psychological Studies.(Edited by P.Milvy) Ann. New York Acad.Sci.

Shellock, F.G and Prentice, W.E. (1985) Warming-up and stretching for improved physical performance and prevention of sports related injuries. Sports Medicine 2, 267-278.

Sjodin, B. and Jacobs, I. (1981) Onset of blood lactate accumulation and marathon running performance. International Journal of Sports Medicine 2, 23-26

Sjodin, B. and Svendenhag, J. (1985) Applied Physiology of marathon running. Sports Medicine 2: 83-89.

Sjogard, G. 1987. Muscle fatigue. Medicine Sports Science 26, 98-109. Karger, Basel.

Smith, T.J. and Fernie, G.R. (1991) Functional biomechanics of the spine. Spine 16, 1197-1203.

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

Stalhammer, H.R., Leskinen, T.P.J., Rautanen, M.T. and Troup. J.D.G. (1992) Shrinkage and psychophysical load ratings in self-paced and forced-paced lifting work and during recovery. Ergonomics 35, 1-5.

Stanitski, C.L. (1982) Low-back pain in young athletes. Physician and Sports Medicine 10: 77-91.

Stratham, T., Gettman, L.R. and Cutler, L.A. (1979) The oxygen cost of an isotonic circuit strength programme (abstract), AAHPER Research Papers p 70.

Strickland, A.L. and Shearin, R.B. (1972) Diurnal height variation in children. Journal of Peadiatrics 6, 1023-1025.

Taylor, J.F. and Twomey, T.F. (1980) Sagittal and horizontal plane movement of the lumbar vertebral column in cadavers and in the living. Rheumatology and Rehabilitation. 19, 223-232.

Temple, C. (1983) Hazards of jogging and marathon running. British Journal of Hospital Medicine March, 237-239.

Troup, J.D.G. (1978) Drivers' back pain and its prevention: a review of the postural, vibratory and muscular factors, together with the problem of transmitted road shock. Applied Ergonomics 9: 207-214.

Troup, J.D.G. (1981) Back and neck injuries. In: Sports fitness and sports injuries. (Edited by T. Reilly) Faber and Faber, London.

Troup, J.D.G. and Edwards, F.C. (1985) Manual handling: a review paper. H.M.S.O., London.

Troup, J.D.G., Foreman, T.K., Baxter, C.E and Brown, D. (1987) The perception of back pain and the role of psychophysical tests of lifting capacity. Spine 12, 645-657.

Troup, J.D.G., Martin, J.W., and Lloyd, D.C.E.F. (1981) Back pain in industry: a prospective survey. Spine 6, 61-69.

Troup. J.D.G., Reilly, T., Eklund. J.A.E., and Leatt, P. (1985) Changes in stature with spinal loading and their relation to the perception of exertion or discomfort. Stress Medicine 1, 303-307.

Twomey, L. and Taylor, J. (1982) Flexion creep deformation and hystersis in the human vertebral column. Spine 7, 116-122.

Twomey, L and Taylor, J.R. (1991) Age related changes of the lumbar spine and spinal rehabilitation. Critical Reviews in Rehabilitation and Medicine 2, 153-169.

Tyrrell, A.R., Reilly, T. and Troup, J.D.G. (1985) Circadian variation in stature and the effects of spinal loading Spine 10, 161-164.

Tzankoff, S.P. and Norris, A.H. (1979) Age-related differences in lactate distribution kinetics following maximal exercise. European Journal of Applied Physiology 42, 35-40.

Valiant, G.A. (1990) Transmission and attenuation of heelstrike accelarations. In: Biomechanics of distance running, Ed. Cavanagh, P.R., Human Kinetics, U.S.A.

Videman, T., Rauhala. H., Asp. S., Lindstrom, K., Cedercreutz, G., Kampii. M., Tola, S. and Troup, J.D.G. (1989) Patient handling skill, back injuries and back pain: an intervention study. Spine, 14, 148-156.

Virgin, W.J. (1951) Experimental investigations into the physical properties of the intervertebral disc. Journal of Bone and Joint Surgery 33-B, 607-611.

Waddell, G. (1982) An approach to back ache. British Journal of Hospital Medicine, Sept. 187-219.

Wallace, P. and Reilly, T. (1991) Spinal shrinkage occurring during simulated golf play. Communication to the First World Scientific Congress of Golf (St.Andrews, July 1991).

Walters, S.D., Sutton, J.R., McIntosh, J.M. and Connolly, C. (1985) The aetilogy of sports injuries: a review of methodologies. Sports Medicine 2, 47-58.

Westgaard, R.H. and Aaras, A. (1985) The effect of improved work-place design on the development of work related musculo-skeletal illness. Applied Ergonomics, 16, 91-97.

White, A.A. and Gordon,S.L. (1982) Symposium on idiopathic low back pain (C.V.Mosby, Miami).

White, A.A. and Gordon,S.L. (1982) Synopsis: workshop on idiopathic low-back pain. Spine 7, 141-149.

White, T.L. and Malone, T.R. (1990) Effect of running on intervertebral disc height. Journal of Orthopaedic and Sports Physical Therapy 12, 139-146.

Wilby, J., Linge, K., Reilly. T. and Troup, J.D.G. (1987) Spinal shrinkage in females: Circadian variation and the effects of weight-training. Ergonomics 30, 47-54.

Williams, J.P.G. (1980) Biomechanical factors in spinal injuries. British Journal of Sports Medicine 14, 14-17.

Wilmore, J.H., Parr, R.B., Ward, P., Vodak, P.A., Barstow, T.J., Pipes, T.V., Grimditch, G. and Leslie, P. (1978) Energy cost of circuit weight-training, Medicine and Science in Sports and Exercise 10, 75-78.

Wilmore, J.H., Parr, R.B., Girandola, R.N., Ward, P., Vodak, P.A., Barstow, T.J., Pipes, T.V., Romero, G.T. and Leslie, P.(1978) Physiological alterations consequent to circuit weight-training, Medicine and Science in Sports and Exercise 10, 79-84.

Winter, D.A. (1979) Biomechanics of Human Movement John Wiley, New York.

Yang, J.F. and Winter, D.A. (1984) Electromyographic amplitude normalization methods: improving their sensitivity as diagnostic tools in gait analysis. Archives of Physical Medicine Rehabilitation 65, 517-521.

APPENDIX 1. DISTANCE RUNNING INJURIES QUESTIONNAIRE

DISTANCE RUNNING INJURIES QUESTIONNAIRE

PLEASE WOULD YOU SPARE A LITTLE OF YOUR TIME TO ANSWER A FEW QUESTIONS ON RUNNING INJURIES.

THE FOLLOWING QUESTIONS REQUIRE EITHER:

a) A YES/NO ANSWER. (RING THE ANSWER THAT YOU REQUIRE)
b) A TICK IN THE APPROPRIATE OPTION.
c) A SHORT SENTENCE. (PLEASE WRITE CLEARLY)
d) A NUMERICAL ANSWER. (PLEASE USE FIGURES NOT WORDS)

IF YOU ARE UNSURE OF ANY TIMES AND DATES PLEASE ENTER AS CLOSE AN ESTIMATE AS POSSIBLE.

THANK YOU FOR YOUR COOPERATION.

IF YOU ARE WILLING TO TAKE PART IN FURTHER SCIENTIFIC STUDY, WHICH WOULD INVOLVE A PERSONAL FITNESS ASSESSMENT AT LIVERPOOL POLYTECHNIC SPORTS SCIENCE LABORATORY, PLEASE TICK ON THE DOTTED LINE.......

NAME..

ADDRESS...

DATE OF BIRTH..........................AGE......

SEX.............

OCCUPATION......................................

1) HOW DO YOU RATE THE PHYSICAL EXERTION OF YOUR PRESENT OCCUPATION MOST OF THE TIME?

Please ring: Sedentary Mild Moderate Hard Very Hard

2) HOW DO YOU RATE THE PHYSICAL EXERTION OF YOUR PRESENT OCCUPATION AT THE WORST POSSIBLE TIME?

Please ring: Sedentary Mild Moderate Hard Very Hard

SECTION 1 : TRAINING DETAILS.

1. ARE YOU A MEMBER OF AN ATHLETICS CLUB?

YES/NO

2. HAS YOUR TRAINING SCHEDULE BEEN DEVISED BY A QUALIFIED ATHLETICS COACH?

YES/NO

3. HOW LONG HAVE YOU BEEN RUNNING?

....YEARS/....MONTHS/....WEEKS

4. HOW MANY DAYS PER WEEK DO YOU TRAIN?

....DAYS/WEEK.

5. WHAT IS YOUR AVERAGE WEEKLY MILEAGE?

....MILES PER WEEK.

6. GIVE A TYPICAL WEEKS TRAINING BY TICKING THE APPROPRIATE WORD IN EACH COLUMN.
STATE THE NUMBER OF MILES YOU RUN.
INDICATE THE TIME OF DAY WHEN YOU RUN BY FILLING IN THE DETAILS ON THE APPROPRIATE LINE.
IF TRAINING MORE THAN ONCE A DAY FILL IN THE DETAILS FOR ALL SESSIONS.

MONDAY	MILES	ROAD	GRASS	SYNTHETIC	STEADY	FARTLEK	INTERVAL
BEFORE 9:00am							
9:00am-12:00am							
12:00am-5:00pm							
5:00pm-9:00pm							
AFTER 9:00pm							

TUESDAY	MILES	ROAD	GRASS	SYNTHETIC	STEADY	FARTLEK	INTERVAL
BEFORE 9:00am							
9:00am-12:00am							
12:00am-5:00pm							
5:00pm-9:00pm							
AFTER 9:00pm							

WEDNESDAY	MILES	ROAD	GRASS	SYNTHETIC	STEADY	FARTLEK	INTERVAL
BEFORE 9:00am							
9:00am-12:00am							
12:00am-5:00pm							
5:00pm-9:00pm							
AFTER 9:00pm							

THURSDAY	MILES	ROAD	GRASS	SYNTHETIC	STEADY	FARTLEK	INTERVAL
BEFORE 9:00am							
9:00am-12:00am							
12:00am-5:00pm							
5:00pm-9:00pm							
AFTER 9:00pm							

FRIDAY	MILES	ROAD	GRASS	SYNTHETIC	STEADY	FARTLEK	INTERVAL
BEFORE 9:00am							
9:00am-12:00am							
12:00am-5:00pm							
5:00pm-9:00pm							
AFTER 9:00pm							

SATURDAY	MILES	ROAD	GRASS	SYNTHETIC	STEADY	FARTLEK	INTERVAL
BEFORE 9:00am							
9:00am-12:00am							
12:00am-5:00pm							
5:00pm-9:00pm							
AFTER 9:00pm							

SUNDAY	MILES	ROAD	GRASS	SYNTHETIC	STEADY	FARTLEK	INTERVAL
BEFORE 9:00am							
9:00am-12:00am							
12:00am-5:00pm							
5:00pm-9:00pm							
AFTER 9:00pm							

7. HOW OFTEN DO YOU RACE?

....

8. DO YOU WARM-UP BEFORE TRAINING?

YES/NO

9. DO YOU WARM-UP BEFORE RACING?

YES/NO

10. HOW IMPORTANT DO YOU REGARD YOUR WARM-UP? (TICK AS APPROPRIATE)

a) VERY IMPORTANT ( )
b) IMPORTANT ( )
c) FAIRLY IMPORTANT ( )
d) UNIMPORTANT ( )

11. DO YOU WARM DOWN AFTER TRAINING?

YES/NO

12. DO YOU WARM DOWN AFTER RACING?

YES/NO

13. HOW IMPORTANT DO YOU REGARD YOUR WARM-DOWN? (TICK AS APPROPRIATE)

a) VERY IMPORTANT ( )
b) IMPORTANT ( )
c) FAIRLY IMPORTANT ( )
d) UNIMPORTANT ( )

14. HOW LONG DOES YOUR WARM-UP LAST?

....MINUTES.

15. HOW LONG DOES YOUR WARM-DOWN LAST?

....MINUTES.

SECTION 2. RUNNING INJURIES.

1. PLEASE TICK ANY AREAS INJURED IN TRAINING IN THE PAST 12 MONTHS.

LOWER BACK.....
PELVIS.........
HIP JOINT......
THIGH..........
HAMSTRINGS.....
KNEE JOINT.....
CALF...........
SHIN...........
ANKLE JOINT....
FOOT...........

2. PLEASE TICK ANY AREAS INJURED IN COMPETITION IN THE PAST 12 MONTHS.

LOWER BACK.....
PELVIS.........
HIP JOINT......
THIGH..........
HAMSTRINGS.....
KNEE JOINT.....
CALF...........
SHIN...........
ANKLE JOINT....
FOOT...........

3. WHAT WAS YOUR MOST SEVERE INJURY?

....

4. HAVE YOU HAD YOUR WORST INJURY SEEN BY:

a) COACH. YES/NO
b) PHYSIOTHERAPIST. YES/NO
c) DOCTOR. YES/NO.
d) HOSPITAL CASUALTY. YES/NO.
e) OTHER. YES/NO.

5. HOW SEVERE WAS YOUR WORST INJURY?

a) NEGLIGIBLE EFFECT. ( )
b) QUALITY OF TRAINING REDUCED. ( )
c) PREVENTED FROM TRAINING. ( )

6. WAS YOUR WORST INJURY CAUSED BY RUNNING?

YES/NO.

IF YES THEN DID IT OCCUR ON:

a) ROAD ( )
b) GRASS ( )
c) SYNTHETIC ( )
d) OTHER ( )

7. DO YOU ATTRIBUTE YOUR WORST INJURY TO ANY OF THE FOLLOWING FACTORS?

a) INADEQUATE FOOTWEAR ( )
b) AN ABRUPT CHANGE OF MILEAGE ( )
c) A CHANGE OF RUNNING SURFACE ( )
d) EXCESSIVE MILEAGE ( )
e) OTHER ( )

8. HOW EXPENSIVE WERE YOUR RUNNING SHOES?

a) LESS THAN £10:00 ( )
b) £10:00-20:00 ( )
c) £20:00-30:00 ( )
d) MORE THAN £30:00 ( )

9. DID YOU RUN ON IMMEDIATELY AFTER INJURY?

YES/NO.

10. DID YOU CONTINUE TO TRAIN IN SPITE OF INJURY?

YES/NO.

11. HOW LONG AFTER INJURY DID YOU SEEK PROFESSIONAL ADVICE?

a) IMMEDIATELY ( )
b) LATER THE SAME DAY ( )
c) NEXT DAY ( )
d) LESS THAN ONE WEEK LATER ( )
e) MORE THAN ONE WEEK LATER ( )
f) NOT AT ALL ( )

12. IN WHICH MONTH DID YOUR WORST INJURY OCCUR?

....

13. AT WHAT TIME OF DAY DID YOUR WORST INJURY OCCUR? (TICK ONLY ONE OPTION)

a) BEFORE 9:00am ( )
a) 9:00am-12:00am ( )
b) 12:00am-5:00pm ( )
c) 5:00pm-9:00pm ( )
d) AFTER 9:00pm ( )

*** IF YOU HAVE LISTED "LOWER BACK" IN YOUR ANSWERS TO QUESTIONS 1 AND/OR 2 IN SECTION 2, ANSWER SECTION 3 ENTITLED "LOWER BACK PAIN" ***

SECTION 3 : LOWER BACK PAIN.

*** THIS SECTION ONLY CONCERNS PARTICIPANTS WITH LOWER BACK PAIN i.e. PAIN BETWEEN THE MID-BACK AND THE BUTTOCKS ***

1. WHEN DID YOU FIRST EXPERIENCE LOWER BACK PAIN?

DATE..../..../....

2. DID YOUR FIRST INCIDENCE OF LOWER BACK PAIN OCCUR:

a) SUDDENLY ( )
b) GRADUALLY ( )

3. IF YOUR BACK PAIN ONSET WAS SUDDEN, STATE THE ACTIVITY BEING PERFORMED AT THE TIME OF INJURY:

....

4. DO YOU HAVE LOWER BACK PAIN NOW?

YES/NO

5. HOW OFTEN DO YOU GET LOWER BACK PAIN? (TICK ONLY ONE OPTION)

a) DAILY ( )
b) ONCE A WEEK ( )
c) ONCE A MONTH ( )
d) A FEW TIMES A YEAR ( )
e) LESS THAN ONCE A YEAR ( )
f) NO FURTHER ATTACKS ( )

6. IF LOWER BACK PAIN OCCURS REGULARLY, WHEN IS THE PAIN WORST? (TICK ONLY ONE OPTION)

a) ON RISING ( )
b) POST RISING-12:00am ( )
c) 12:00am-5:00pm ( )
d) 5:00pm-9:00pm ( )
e) AFTER-9:00pm ( )
f) WHILST IN BED ( )
g) CONSTANT ( )

7. DO ANY OF THE FOLLOWING ACTIVITIES MAKE THE PAIN WORSE?

a)LIFTING ( )
b)WALKING ( )
c)RUNNING ( )
d)OTHER SPORTS (SPECIFY)................
e)STANDING STILL ( )
f)SITTING DOWN ( )
g)LYING DOWN ( )
h)BENDING FORWARD ( )
i)OTHER (SPECIFY).......................

8. IS THERE ANY ACTIVITY OR POSTURE THAT RELIEVES THE PAIN?

(SPECIFY).........................

APPENDIX 2. WEIGHT-TRAINING INJURIES QUESTIONNAIRE

EIGHT-TRAINING INJURIES QUESTIONNAIR

PLEASE WOULD YOU SPARE ABOUT 10 MINUTES OF YOUR TIME TO ANSWER A FEW QUESTIONS ON INJURIES.

THE FOLLOWING QUESTIONS REQUIRE EITHER:

a) A YES/NO ANSWER. (RING THE ANSWER THAT YOU REQUIRE)
b) A TICK IN THE APPROPRIATE OPTION.
c) A SHORT SENTENCE. (PLEASE WRITE CLEARLY)
d) A NUMERICAL ANSWER. (PLEASE USE FIGURES NOT WORDS)

IF YOU ARE UNSURE OF ANY TIMES AND DATES PLEASE ENTER AS CLOSE AN ESTIMATE AS POSSIBLE. ALL INFORMATION WILL BE TREATED IN THE STRICTEST CONFIDENCE.

THANK YOU FOR YOUR COOPERATION.

NAME.......................................

ADDRESS....................................

....

DATE OF BIRTH..........................AGE.....

OCCUPATION.................................

) HOW DO YOU RATE THE PHYSICAL EXERTION OF YOUR PRESENT OCCUPATION MOST OF THE TIME?

Please ring: Sedentary Mild Moderate Hard Very Hard

) HOW DO YOU RATE THE PHYSICAL EXERTION OF YOUR PRESENT OCCUPATION AT THE HARDEST POSSIBLE TIME?

Please ring: Sedentary Mild Moderate Hard Very Hard

ECTION 1. TRAINING HABITS

WHAT IS THE NAME OF THE CLUB OF WHICH YOU ARE A MEMBER?

....

HAS YOUR TRAINING SCHEDULE BEEN DEVISED BY A QUALIFIED WEIGHT -TRAINING INSTRUCTOR?

YES/NO

HOW LONG HAVE YOU BEEN WEIGHT-TRAINING?

....YEARS/....MONTHS/....WEEKS

HOW MANY TIMES PER WEEK DO YOU TRAIN?

....TIMES/WEEK.

HOW LONG IS YOUR AVERAGE TRAINING SESSION?

....MINUTES PER SESSION.

WHY DID YOU TAKE UP WEIGHT-TRAINING?

Please ring:
a) To lose weight.
b) To gain weight.
c) To gain strength.
d) To improve general fitness
e) Other (Give reason) ....
....

DO YOU WARM-UP BEFORE TRAINING?

YES/NO

HOW IMPORTANT DO YOU REGARD YOUR WARM-UP? (TICK AS APPROPRIATE)

a) VERY IMPORTANT. ( )
b) IMPORTANT. ( )
c) FAIRLY IMPORTANT. ( )
d) UNIMPORTANT. ( )

DO YOU WARM DOWN AFTER TRAINING?

YES/NO

HOW IMPORTANT DO YOU REGARD YOUR WARM-DOWN? (TICK AS APPROPRIATE)

a) VERY IMPORTANT. ( )
b) IMPORTANT. ( )
c) FAIRLY IMPORTANT. ( )
d) UNIMPORTANT. ( )

HOW LONG DOES YOUR WARM-UP LAST? ....MINUTES.

HOW LONG DOES YOUR WARM-DOWN LAST? ....MINUTES.

CTION 2. WEIGHT-TRAINING INJURIES.

1. PLEASE TICK ANY AREAS INJURED DURING TRAINING IN THE PAST 12 MONTHS.

NECK	( )
SHOULDER	( )
UPPER ARM	( )
ELBOW	( )
FOREARM	( )
WRIST	( )
HAND	( )
CHEST	( )
RIBS	( )
ABDOMINALS	( )
UPPER BACK	( )
LOWER BACK	( )
PELVIS	( )
HIP JOINT	( )
GROIN	( )
THIGH	( )
HAMSTRINGS	( )
KNEE JOINT	( )
CALF	( )
SHIN	( )
ANKLE JOINT	( )
FOOT	( )

2. WHAT WAS YOUR MOST SEVERE INJURY?

....

3. HAVE YOU SOUGHT PROF~~F~~ESSIONAL ADVICE ABOUT YOUR WORST INJURY FROM:

a) COACH. YES/NO
b) PHYSIOTHERAPIST. YES/NO
c) OWN DOCTOR. YES/NO.
d) HOSPITAL CASUALTY. YES/NO.
e) OTHER. YES/NO. PLEASE STATE PROFESSION:..........

4. HOW SEVERE WAS YOUR WORST INJURY? (TICK APPROPRIATE ANSWER)

a) NEGLIGIBLE EFFECT. ( )
b) QUALITY OF TRAINING REDUCED. ( )
c) PREVENTED FROM TRAINING. ( )

5. HOW LONG AFTER INJURY DID YOU SEEK PROFESSIONAL ADVICE?(TICK AS APPROPRIATE)

a) IMMEDIATELY. ( )
b) LATER SAME DAY. ( )
c) NEXT DAY. ( )
d) LESS THAN ONE WEEK LATER. ( )
e) MORE THAN ONE WEEK LATER. ( )
f) NOT AT ALL. ( )

AT WHAT TIME OF DAY DID YOUR WORST INJURY OCCUR?(TICK AS APPROPRIATE)

a) BEFORE 9:00am. ( )
b) 9:00am - 12:00pm. ( )
c) 12:00pm - 5:00pm. ( )
d) 5:00pm - 9:00pm. ( )
e) AFTER 9:00pm. ( )

~'5

LOW BACK PAIN QUESTIONNAIRE (Only answer this section if you have had low back pain)

PLEASE NOTE: In the following questions LOW BACK PAIN refers to pain experienced between the mid-back and buttocks due to INJURY, OVER-EXERTION, BAD POSTURE, etc. (In females - not back pain due to menstruation).

HAVE YOU EVER HAD LOW BACK PAIN? YES/NO (Delete)
If YES, please complete all the questions.
If NO, please return the questionnaire to the researchers.

1) WHEN WAS THE FIRST EPISODE? DATE: ....

   HOW BAD WAS IT? ....(Please insert a number from the scale provided)

   WERE YOU ABSENT FROM WORK? YES/NO (Delete) If so, how long? .... day

2) WHEN WAS THE WORST EPISODE? DATE ....

   HOW BAD WAS IT? ......(Please insert a number from the scale provided)

   WERE YOU ABSENT FROM WORK? YES/NO (Delete) If so, how long? .... days.

3) WHEN WAS THE MOST RECENT EPISODE? DATE:.......................

   HOW BAD WAS IT? .... (Please insert a number from the scale provided)

   WERE YOU ABSENT FROM WORK? YES/NO (Delete) If so, how long? .....days.

4) DID THE PAIN DEVELOP

   SUDDENLY/GRADUALLY (Delete)

5) IF SUDDENLY, WERE YOU AT WORK AT THE TIME YES/NO (Delete)

   and WHAT ACTIVITY CAUSED THE PAIN? ....

6) DO YOU HAVE BACK PAIN AT THIS MOMENT? YES/NO (Delete)

7) HOW OFTEN DO YOU GET BACK PAIN NOW? (Please circle)

   DAILY
   ONCE A WEEK
   ONCE A MONTH
   A FEW TIMES A YEAR
   LESS THAN ONCE A YEAR
   ONE EPISODE AND NO FURTHER EPISODES

8) IF REGULARLY, (i.e. DAILY or ONCE A WEEK) WHAT TIME OF THE DAY IS THE PAIN WORST? (Please circle)

   IMMEDIATELY AFTER RISING
   DURING THE MORNING
   DURING THE AFTERNOON
   DURING THE EVENING
   DURING THE NIGHT
   CONSTANT

   AND HOW BAD IS THE PAIN <u>AT EACH</u> OF THE FOLLOWING TIMES? (Please use scale provided)

   IMMEDIATELY AFTER RISING ....
   DURING THE MORNING ....
   DURING THE AFTERNOON ....
   DURING THE EVENING ....
   ....

9) HAVE YOU EVER CHANGED JOBS BECAUSE OF THE LOW BACK PAIN?

YES/NO (Delete)

If YES, How many times ....

10) DOES ANY ACTIVITY EASE THE PAIN? YES/NO (Delete)

If YES, what activity? ....

11) DOES ANY ACTIVITY WORSEN THE PAIN? YES/NO (Delete)

If YES, what activity? ....

12) HAS THE LOW BACK PAIN AFFECTED YOUR ABILITY TO PERFORM NORMAL DAILY ACTIVITIES? (not including sport).

YES/NO (Delete)

13) HAS LOW BACK PAIN AFFECTED YOUR ABILITY TO PERFORM SPORTING ACTIVITIES? (Please circle)

No sporting involvement	Unable to perform sport because of pain	Able, but restricts performance	Unknown

14) DO YOU TAKE ANY PAIN RELEIVING MEDICATION?

YES/NO (Delete)

If YES, please state ....

....

....

15) HAVE YOU PREVIOUSLY HAD SURGERY ON THE BACK?

YES/NO (Delete)

APPENDIX 3. EXAMPLE PAGE FROM TRAINING DIARY

LIVERPOOL POLYTECHNIC
Rector Peter Toyne BA FBIM
FACULTY OF SCIENCE

Dear runner,

Thank you for volunteering to take part in this study. Our aim is to collect data on distance runners training regimes and relate these to injury rates. Hopefully, we will be able to establish a relationship between injuries and their causes.

In order to do this, I have provided you with a training diary which I would like you to keep for 9 months, starting on January 1st 1988 and finishing on September 30th 1988.

Each day is divided into two columns:

Column 1: Training details and Column 2: Injury problems

The following information is required:

1) Training details:
   - Date
   - Time of day
   - Number of miles
   - Time taken
   - Running surface (road, synthetic, grass)
   - Type of training (steady, interval, fartlek)
   - Include rest days (if any!!) as part of training

2) Injury details - state the site of injury (do not attempt to give a diagnosis unless you have seen a doctor or physiotherapist).
   - if any injury is a recurrence of an old problem, follow the name of the injury with an R e.g. (Pulled hamstring - R)
   - please state which leg is injured!
   - Include any information on illnesses which affect your performance.

Be as brief as you can. If possible avoid long sentences - one word or a short phrase will be sufficient in most cases.

I also enclose a short questionnaire on running injuries. This will enable us to differentiate between 'new' and 'old' injuries. Please return this as soon as possible in the stamped addressed envelope provided.

ALL INFORMATION GIVEN WILL BE TREATED IN THE STRICTEST CONFIDENCE.

Thank you for your cooperation. If you have any queries don't hesitate to contact me on 051 207 3581 Ext. 2113. I look forward to hearing from you. Good luck with your training.

Cont'd........

Head of Department of Sport and Recreation Studies · F H Sanderson BEd MA PhD
BYROM STREET · LIVERPOOL · L3 3AF
TELEPHONE · 051-207 3581 ext

Yours sincerely,

Gerard Garbutt
BSc (Hons) MSc.

P.S. It is important that you try to fill in the diary details if possible, as long delays decrease the accuracy of your account.

EXAMPLE PAGE

TRAINING DETAILS	INJURY PROBLEMS and ILLNESSES
SUNDAY August 16th	
10.00 am Road Run	No problems
5 miles race pace	
32 minutes	
MONDAY August 17th	
5.00 pm	Slight pain in heel
8 miles steady	Did not affect running
56 minutes	
TUESDAY August 18th	
6.30 pm internal training	No problems
Track 2 mile warm-up	
4 x 800 m. 2 mile warm-down	
WEDNESDAY August 19th	
REST DAY	
THURSDAY August 20th	
8.00 am Road Run	Aggravated heel injury
10 miles	but did not affect training
65 minutes	
FRIDAY August 21st	
5.00 pm Road Run	No problems
5 miles steady	
35 mins	
SATURDAY August 22nd	
10.00 am 10 K race	Felt Great!!
Time – 37 mins 42 secs	

APPENDIX 4. RATING OF PERCEIVED EXERTION AND BACK PAIN RATING SCALES

BORG'S (1970) PERCEIVED EXERTION RATING 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.

ELEVEN POINT LOWER BACK PAIN RATING SCALE

0 NO PAIN

1 EXTREMELY MILD PAIN

2 VERY MILD PAIN

3 MILD PAIN

4 FAIRLY MILD PAIN

5 MEDIUM PAIN

6 FAIRLY SEVERE PAIN

7 SEVERE PAIN

8 VERY SEVERE PAIN

9 EXTREMELY SEVERE PAIN

10 WORST PAIN IMAGINABLE

Appendicies 5 to 10 not available in this digital copy