

SPINAL LOADING DURING CIRCUIT WEIGHT-TRAINING AND RUNNING

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ABSTRACT

Spinal shrinkage was used as an indicant of loading on the spine in circuit weight-training and running regimes. The loss of stature during two sets of a circuit of weight-training ($n = 10$), a 6 km run by novices ($n = 9$) and a 25 km run by trained runners ($n = 7$) was assessed in male subjects. Shrinkage was not significantly different between the weight-training regime and the 6 km run by novices, mean losses being 5.4 and 3.25 mm respectively. The rate of height loss in the experienced runners was 2.35 mm over 6 km run at 12.2 km.h⁻¹, representing 0.4 mm.km⁻¹ over the 6 km run, this shrinkage rate being continued over the last 19 km run at 14.7 km.h⁻¹. The loss of height could not be predicted from a set of covariates. The magnitude of the circadian variation, mean 14.4 mm, exceeded the change in height during the 25 km run. The diurnal variation conformed to a cosine function, though a better fit was obtained with a power function equation. A marked diurnal pattern was also observed in lumbar extension. Though reversal of spinal shrinkage was observed during a night's sleep, no significant recovery occurred during a 20 min resting period immediately following the exercise regimes. These results have implications for the warm-up and timing of exercise regimes that impose significant loading on the spine.

INTRODUCTION

Spinal loading occurs in a range of sporting activities. The mechanisms of injury to the spine in sport have been outlined by Kazarian (1981) and Troup (1981). An account of back pain in patients at an athletes' clinic at the Middlesex Hospital was reported by Cannon and James (1984). The cause of back pain is often insidious, dysfunction of the disc being frequently suggested as a major causal factor (Nachemson, 1976). The nucleus of the disc and the epiphyseal plates are especially vulnerable as they have no innervation and can be injured without pain (Troup, 1979).

The vertebral column may be subjected to loading by gravity, changes in motion, truncal muscle activity, external forces and external work (Troup, 1979), all factors that can be involved during exercise. When the compressive load exceeds the interstitial osmotic pressure of the tissues of the disc, water is exuded through the disc wall. This results in a loss of disc height and thus a loss of stature (Hirsch, 1955). The magnitude of spinal shrinkage would therefore reflect the degree of loading induced; this index has been employed by researchers (e.g. Eklund and Corlett, 1984) for assessment of spinal loading in industrial contexts.

Examples of exercise regimes commonly used for general fitness purposes which load the spine include weight-training and running. The former is often conducted as a circuit with weight-lifting exercises and this type of regime has been shown to produce an effective training stimulus for the cardiovascular system (Reilly and Thomas, 1978; Gettman et al, 1982). During a dead lift of 10 kg and 40 kg performed repeatedly for 20 mins, reductions in stature of 6.9 mm and 14.5 mm respectively were reported (Tyrrell et al, 1985). Greater losses in stature were found to occur when dynamic rather than static loadings were involved. However, there appears to be no information

available on the extent of spinal shrinkage when circuit weight-training is undertaken.

During running the force generated at the point of heel strike is usually in excess of 2000 N (Lees and McCullagh, 1984), and as the force is transmitted to the spine significant spinal loading may be implicated. This is borne out by the magnitude of intra-abdominal pressure changes which increase with the speed of running (Grillner et al, 1978), intra-abdominal pressures being related to lumbosacral loading. Various factors such as the total distance covered and the experience of the runner, may influence the intensity of these effects.

In this study measurements were made of the spinal shrinkage incurred (i) in performing a circuit weight-training regime and (ii) during a 6 km run by trained and novice runners, and during a 25 km run by the trained group. As forces load the spine in the course of normal daily habitual activity (Reilly et al, 1984; Tyrrell et al, 1985), results of the exercise regimes were compared with the circadian variation in stature.

METHODS

Apparatus

The apparatus used for measuring stature was that described by Tyrrell et al (1985), with the modification that the incline employed was 8° to the vertical. Its design was an adaptation of the device reported by Eklund and Corlett (1984). Accurate measurements of the change in posture are possible when the placement of selected anatomical landmarks against the back wall of the metal frame, shown in Fig. 1, is standardised (Reilly et al, 1984). Measurement accuracy was within 0.01 mm and measurements were made once subjects were suitably trained to hold a relaxed posture within the frame.

Subjects

The subjects used were all healthy males who had no history of back pain. Subjects in the weight-training study ($n = 10$) were aged 19.8 (\pm SD = 1.9) years and weighed 68.4 (\pm SD = 5.3) kg, their height being 1.74 (\pm SD = 0.05) m.

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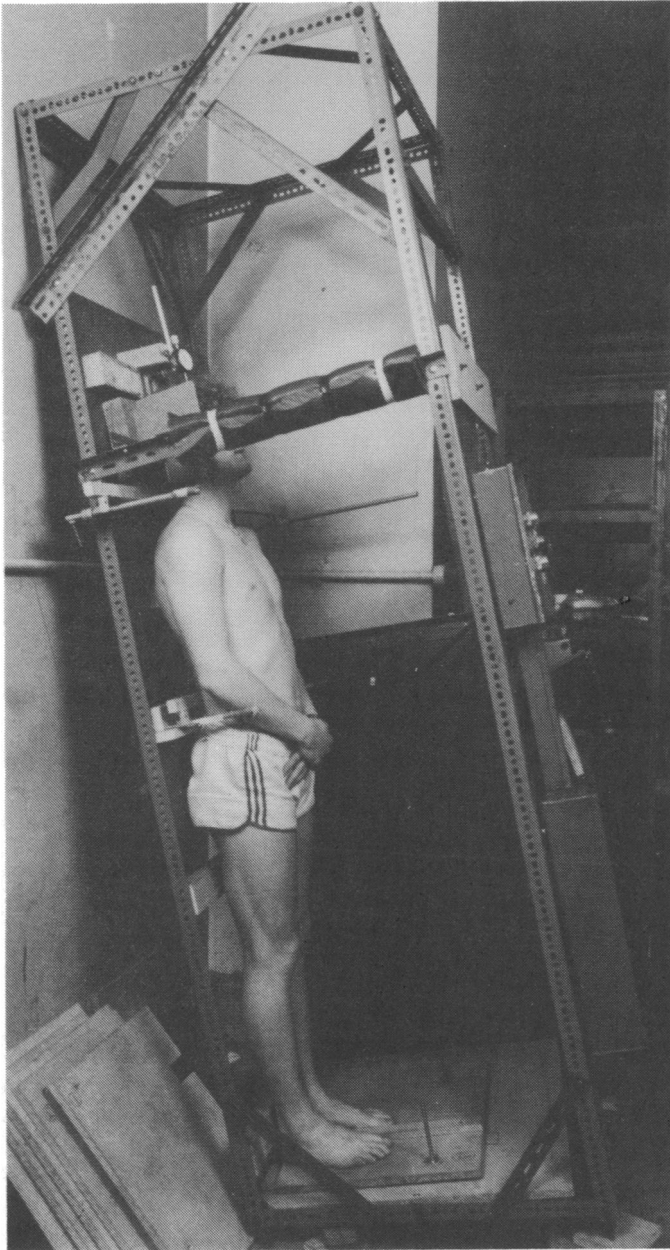


Fig. 1: Apparatus for measurement of stature with the subject in position.

Subjects in the running experiment consisted of nine novice runners and seven trained endurance runners whose regular weekly mileage exceeded 50 (80 km week⁻¹). The novices were aged 19.9 (\pm SD = 2.2) years, weighed 69.4 (\pm SD = 4.0) kg and their mean height was 1.74 (\pm SD = 0.05) m. Corresponding values for the experienced runners were 31.0 (\pm SD = 10.0) years, 62.4 (\pm SD = 5.3) kg and 1.72 (\pm SD = 0.04) m respectively. The circadian variation study involved 11 subjects aged 20.3 (\pm SD = 2.3) years, body weight was 66.7 (\pm SD = 4.9) kg and height was 1.74 (\pm SD = 0.05) m: 10 of these subjects were recruited from the weight-training sample.

Measurement procedure

Subjects entered the apparatus wearing only shorts. Each measurement period was timed with a Casio electronic stopwatch. During the first 4 secs the subject settled into the relaxed posture required for measurements: electronic checks on this position were integrated into the apparatus as explained by Tyrrell et al (1985) and measurements were then made in the ensuing 16 secs. Three observations were made on each occasion and the mean value was used to

record the change in height.

Prior to participating in any of the experiments each subject was required to produce 10 successive measurements with a standard deviation of less than 0.5 mm. This needed 3 practice sessions on average, during which 90 measurements were made on each subject. It was noted that the endurance athletes were able to conform to experimental requirements significantly sooner than the untrained runners ($P < 0.05$).

Exercise regimes

For the circuit weight-training study nine weightlifting exercises were selected. Each one either directly loaded the spine or involved the muscles of the back. The regime is illustrated in Fig. 2 while the details of the repetitions used are contained in Table 1. The weights and number of repetitions were chosen so that the circuit was uniform for all subjects. One experimenter (PL) demonstrated each exercise and written instructions were provided at each exercise station. Two circuits were performed, the regime consisting in total of 18 exercises, completion of which was predicted to take 25 mins. On completion of the circuits, perceived exertion was rated using the Borg (1970) scale. As soon as subjects' breathing recovered and they were able to relax — this usually took about 3 mins — measurements of stature were made every 5 mins for 20 mins, during which time they recovered from the exercise while standing unsupported.

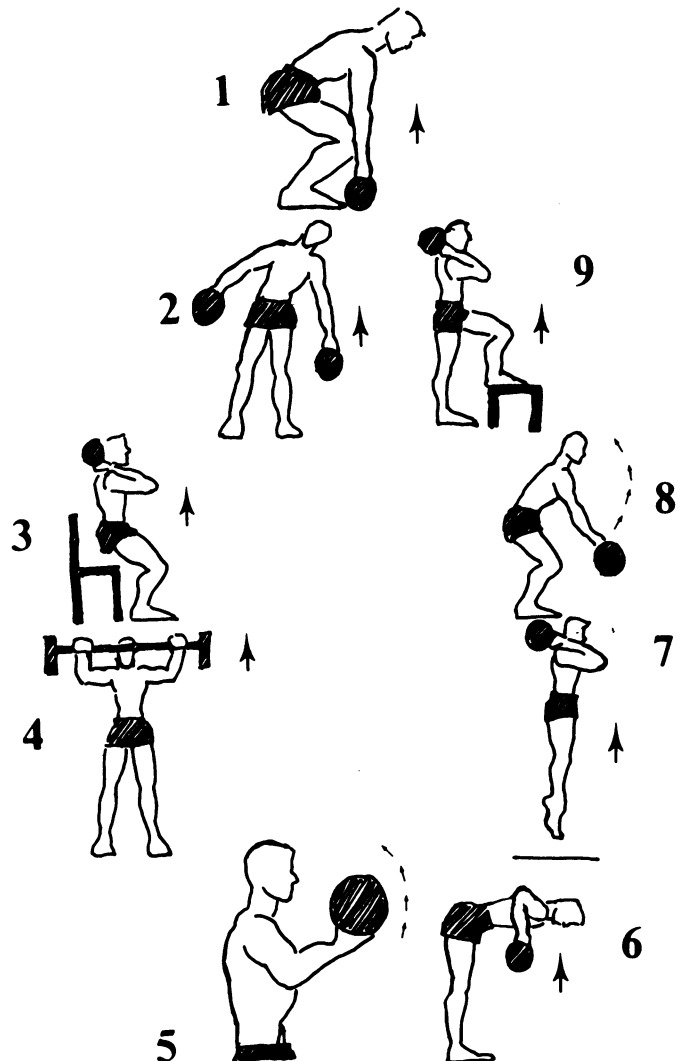


Fig. 2: The exercise constituting the circuit training regime.

TABLE I
Prescription of the circuit training regime

Exercise		Weight (kg)	No. of Repetitions
Number	Name		
1	Dead Lift	32	15
2	Lateral Bends	20 x 2	15 x 2
3	Squat	32	15
4	Military Press	14	15
5	Arm Curls	14	15
6	Bent Over Rowing	14	15
7	Leaping Squat	—	20
8	Dumbbell Swing	20	20
9	Step-Ups onto a Bench	22	20

In the running experiment the novices ran a total of 6 km and the experienced runners did 25 km. The 6 km run was performed at a speed of 12.2 km.h⁻¹ (approximately 8 mins per mile) for 29 mins. As soon as the subjects had sufficiently recovered and could breathe in a relaxed fashion for measurement of stature to be made (usually about 3 mins), they were measured at 5 min intervals for 20 mins, during which time they were standing unsupported but otherwise inactive. The trained runners also covered this distance at a similar speed, at which point the run was halted so that measurements could be made to compare with the novices: subjects then resumed running for a further 19 km at 14.7 km.h⁻¹ (approximately 6.5 mins per mile), thus completing the 25 km distance. Subjects then assumed a standing recovery posture and the same measurements were made as in the novices. Perceived exertion was established during the last minute of exercise in all three runs.

Before each exercise regime the resting heart rate was measured by palpation of the carotid artery during a 5 min period of sitting relaxed. Post-exercise heart rate was determined by a similar procedure but over a 6 sec period immediately exercise was terminated. The starting time of each activity was controlled for time of day as far as possible, the mean starting time being between 09.30 and 10.30 hours.

Circadian variation and measurement curves

The subjects of the weight-training study plus one other participated in the investigation of circadian variation in stature. Measurements were made over a 24 hour period at the following times:— 03:45, 07:30, 08:15, 09:00, 10:00, 12:00, 16:00, 20:00 and 24:00 hours. These times were chosen to permit replication of the work of Reilly et al (1984). Subjects retired for sleep after the measurement at midnight and were awakened in mid-sleep for measurement at 03.45 hours. In these subjects measurements were also made of the lumbar spinal curvature in maximal flexion and extension, using a modified Loebli goniometer.

The reliability of the method of measuring stature was determined by taking ten consecutive measurements in each of the weight-training subjects, on all the distance runners and on the subjects in the study of circadian variation. The standard error of measurement was calculated to be 0.025 mm when data from all groups were pooled. The methodology was therefore taken to be highly reliable.

Statistical analysis

The effects of the exercise regimes on changes in height were analysed using a factorial ANOVA model (Nie et al, 1970). This incorporated terms to account for interactions between subjects and regimes, and between subjects, regimes and times during the experiment including the recovery period. The relationships between changes in height and perceived exertion were examined using the Pearson Product moment method.

Multiple regression analysis was used to determine the predictability of the change in height from easily obtainable data. Subjects' stature and weight measured before the treatment commenced were included among the predictors along with age, heart rate and perceived exertion at the end of exercise.

Using the Kelvin unit model of the disc, as presented by Burns and Kaleps (1980), an experimental equation was derived to predict the changes in height with time. The spinal load was assumed to be constant and so the single Kelvin unit model which has no elastic response was chosen. This replicates the procedure used by Eklund and Corlett (1984).

Circadian variation in stature was examined by cosinor analysis. The model used was that proposed by Nelson et al (1979). Where a significant cosine function was established, the computer program using a DEC-20 system examined whether a non-sinusoidal fit improved the result.

RESULTS

Exercise regimes

On average the weight-training regime took 24.6 min and resulted in a height loss of 5.4 (\pm SD = 1.7) mm. Mean perceived exertion was 14.6 (\pm SD = 2), corresponding to a rating of 'hard'. Perceived exertion was not significantly correlated to the height lost in either the loading or the recovery phases ($P > 0.05$).

During the 6 km run the mean height loss of novices was 3.25 mm. The mean shrinkage of 2.35 mm in the trained group was not significantly different from this ($P > 0.05$). The mean shrinkage during the 19 km that followed was 7.8 mm. Mean rating of perceived exertion was 13.2 (\pm SD = 3.3) for the novices and 9.1 (\pm 1.4) for the good runners at 6 km, 12.3 (\pm 2.1) at 25 km. The greater the novices' feeling of exertion during the run, the more height they lost ($P < 0.05$), and the less was regained afterwards ($P < 0.001$). This relationship was not evident in the trained runners.

Shrinkage with the different regimes is shown in Fig. 3. Analysis of the complete data set by ANOVA revealed significant effects of time ($F = 60.9$; $P < 0.001$) and regimes within time ($F = 5.25$; $P < 0.01$). None of the interaction terms was significant. The difference between the height loss induced by the circuit training and that by the novices' 6 km run was non-significant. The significant difference in shrinkage between the 6 km and 19 km runs in the trained group was explained by the distance run.

The multiple regression equation, examining the contribution of covariates (age, stature, body weight, perceived exertion and heart rate) to the change in height, failed to produce a significant result ($P > 0.05$). This was

despite the differences in age between the novice and experienced runners.

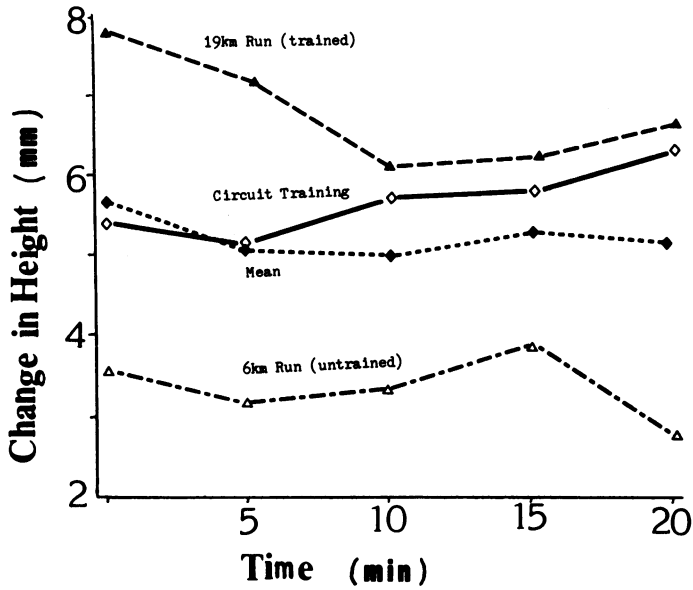


Fig. 3: The mean loss of height (\pm SE) with the various exercise regimes. The 19 km run represents the second part of the regime of the trained athletes.

The change in height during the standing recovery was then considered using ANOVA. The mean loss after circuit training was 0.7 mm, the gain after running was 0.75 mm for the novices and 1.45 mm for the trained runners (Fig. 4). There was no significant effect of time ($F = 0.02$; $P > 0.05$), subject ($F = 0.77$; $P > 0.05$) or regime ($F = 1.65$; $P > 0.05$). Nor did the recovery rate depend on the amount of height lost in the previous exercise. The second order interaction for subjects \times regime \times time was non-significant ($F = 0.03$; $P > 0.05$).

Circadian variation

The mean change in height over 24 hours showed a clear diurnal pattern (Fig. 5). The peak to trough change was 14.4 mm or 0.83% of the mean stature. Altogether 38.4% of

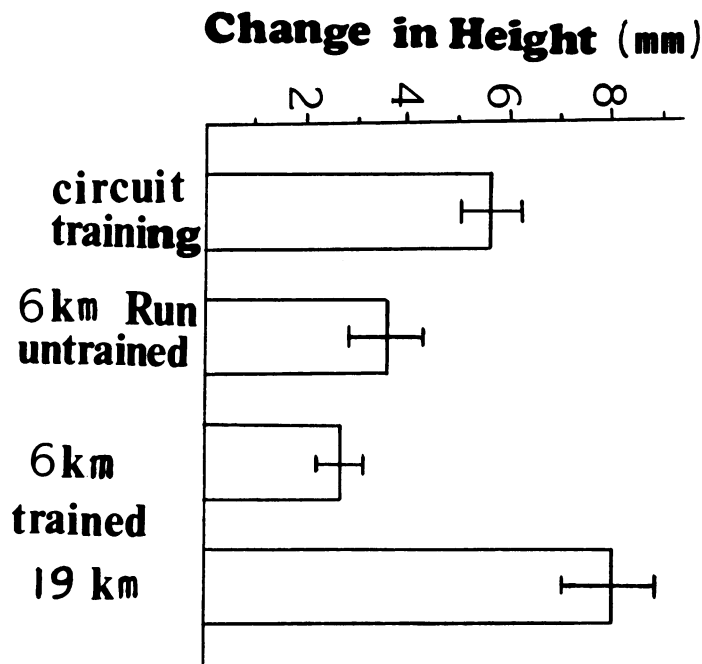


Fig. 4: Recovery of the change in height for each of the three regimes. The mean recovery values are also shown.

the height lost was in the first 1.5 hours after awakening, 60.8% within 2.5 hours of rising. The height lost during waking hours was regained completely during sleep. In the first half of the night's sleep, 68% of the height lost was restored.

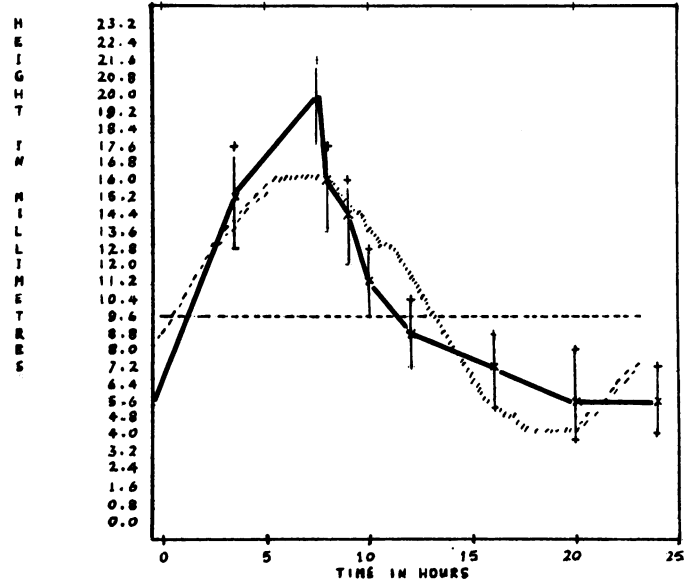


Fig. 5: The circadian variation in height, the midnight baseline being shown as 5.6 mm on the vertical axis. The cosine curve fitted to the observations and the 95% confidence limits are also shown.

Cosinor analysis of the change in height over 24 hours showed a highly significant result ($F = 64.4$; $P < 0.001$). However, the cosine curve did not provide the best fit ($F = 10.75$; $P < 0.001$). Further analysis with an 'exponential regression' function yielded the equation:-

$$H = 1249.7 + 2.5 e^{-0.192t}$$

where H is loss of height in mm and t indicates time.

The goodness of fit of the power function is indicated by the r value of 0.99. The observations and the values predicted by the equation are in Fig. 6.

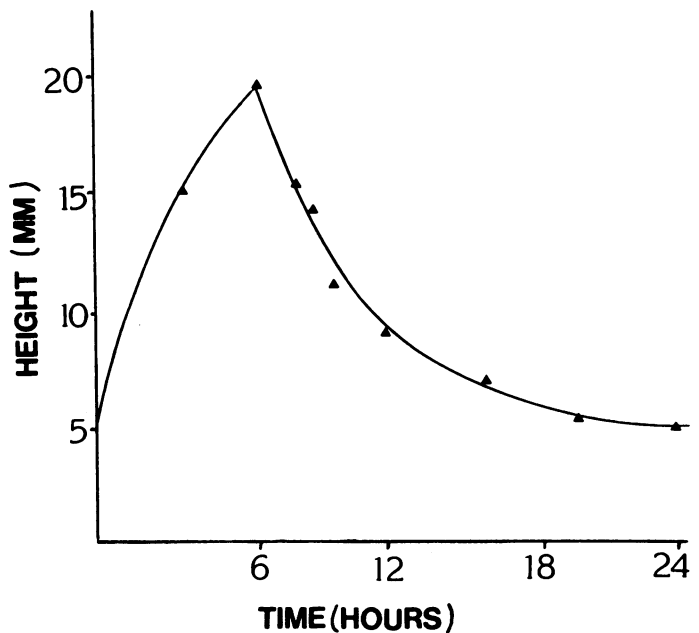


Fig. 6: The conformity of the diurnal variation to a power function equation.

There was no significant variation in lumbar flexion over 24 hours. Lumbar extension did show a marked change ($F = 7.97$; $P < 0.01$); but did not conform to a cosine function. The peak was at 10:00 hours and values were elevated during the day until evening. The mean difference between peak and trough values for spinal extension was 8.5° .

DISCUSSION

The present study showed that circuit training with weights and distance running cause reductions in height which could be measured sensitively and reliably with appropriate methodology. It is assumed that the loss of height is due to an increase in spinal loading. This raises the intradiscal pressure and causes fluid to be expelled, resulting in a reduction in disc height. The assumption is that in all measurements of height, variations are due to changes in disc height. In a vertical plane the cartilage in joints and soft tissues covering the head and the soles of the feet may all be compressible. However, the total height of the intrajoint cartilage is small and the degree of compression is thought to be negligible. The tissue covering the scalp is very thin and the plate on the end of the micrometer used for measurement would reduce indentation to an insignificant level. Tissue on the soles of the feet is likely to compress on standing but reach an equilibrium quickly so that it is unlikely to affect results. Consequently the observed changes in height can be considered to reflect the magnitude of spinal loading.

The similarity of the results for the 6 km run and for the weight-training regime was probably not fortuitous. The regimes were approximately equal in duration and they represented typical training practice. The dimensions of the weight-training programme and the noted exertion rating compared favourably with the circuit of weight-training exercises validated for multi-station equipment (Reilly and Thomas, 1978). Similarly, the 6 km run is typical of a training regime advocated for recreational joggers (Pollock et al, 1978).

Results for the circuit training were less than previous observations of static and dynamic loading of the spine for 20 mins reported by Tyrrell et al (1985). The shrinkage in the present study was comparable to the 5.45 mm loss in height due to supporting a 10 kg rucksack or a loss of 5.5 mm for a similarly weighted barbell. The effect of static loading by means of a barbell were found by Tyrrell and co-workers to increase in a linear fashion to a loss of 11.2 mm for a 40 kg weight in 20 mins. Dynamic exercises were found to have more pronounced effects, the losses amounting to 6.9 mm for repeated lifting of a 10 kg barbell at a rate of 12 lifts per minute, the corresponding value for a 40 kg barbell exercise being 14.5 mm. Weights intermediate between those loads were used for the present study but the cycles in activity were much faster, yet the spinal shrinkage was relatively modest.

Of particular interest was the comparison of the experienced runners with the novices. The findings suggest that skill or economy in the running motion do not serve to substantially attenuate the spinal loading. Attention to such factors as selection of appropriate running shoes and running surfaces is needed in both cases. Additionally the trained runners continued to lose height at the same rate throughout the last 19 km of their experimental run.

Marginally higher values for height loss might be anticipated in that period as a result of the greater intensity of the regime after the run was halted at 6 km. The data suggest that the duration of the exercise is a dominant factor in determining the total spinal loading during training runs. Assuming that height is lost at a continuous rate, the present data would predict a shrinkage of about 17 mm in the course of a marathon race. This exceeds the loss incurred throughout the waking day in the current study by 18%.

The power function fitting the data on circadian variation was very similar to that reported by Eklund and Corlett (1984). The magnitude of the circadian variation in the present study was less than the 19.3 mm and 17 mm peak to trough change reported by Reilly et al (1984) and Krämer (1981) respectively. It is clear that in the normal course of the day, sharp discrepancies from this pattern must arise from spells of loading or recovery. The normal trend throughout the day should be taken into consideration when exercise regimes are being prescribed. The spine may be more vulnerable to injury from loading in the evening when it has already lost appreciable disc height. Some form of reversing this prior shrinkage may be advisable before such exercise regimes are performed in the evening. These could include adopting the Fowler posture — lying on the back with thighs at 45° and calves supported horizontally on a chair — for a period prior to exercise or use of gravity inversion as reported by Leatt et al (1985) for unloading the spine.

The results in the present study differ from previous reports in one important respect, namely the failure to regain stature significantly in the standing position after running and circuit training. In the previous reports (e.g. Tyrrell et al, 1985) there have been immediate reversals after the shrinkage from the different forms of spinal loading. Though the mechanism accounting for this difference cannot be identified from present data, it is possible that it may stem from the higher levels of energy expenditure in running and circuit training compared with that in the static loading or lifting exercises previously reported.

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BOOK REVIEW

Title: **SPORTS INJURIES. MECHANISMS, PREVENTION, AND TREATMENT**
Editors: Richard C. Schneider, John C. Kennedy, Marcus L. Plant
Publishers: Williams and Wilkins, Baltimore, London, Los Angeles, Sydney. UK distributors Stonebridge, Bristol
Price: 877 pages ISBN 0-683-07609-4

This is a multi author book concerned with the mechanisms, prevention and treatment of sports injuries. The majority of the authors are from the USA and there is a natural bias towards the more prolonged sports from across the Atlantic.

The book is some 877 pages long, the first 21 chapters are devoted to individual sports and their particular injuries. The second part of the book deals with specific anatomical areas and the diagnosis and management of injuries in these particular areas. This leads to a certain amount of repetition and cross-referencing which is unavoidable but may be a little aggravating to some readers. There are numerous figures and tables, with a subject and author index.

Invariably as it is a multi author book the degree of detail on treatment varies from chapter to chapter. In some chapters there is a comprehensive coverage of management including detailed operative treatment where required whereas in others it would have been beneficial to detail the treatment in greater depth.

There are useful chapters on the 'Use and Abuse of Drugs', 'Cardiopulmonary Resuscitation' and 'Psychological Factors in Sports Injuries'.

This book provides a comprehensive account of the various sports and the management of specific injuries. It is well laid out and well illustrated with a comprehensive range of references at the end of each chapter.

It is a highly recommended book that should be read by all those participating in the looking after and treatment of the sportsman.

M. J. Allen

BOOK REVIEW

Title: **INTRODUCTION TO RADIOGRAPHIC CEPHALOMETRY**
Authors: Alex Jacobson, DMD and Page W. Caufield, DDS
Publishers: Lea and Febiger, Philadelphia. UK distributors Quest-Meridien, Beckenham
Price: £30.00

This is an excellent new text book, with contributions from four leading authorities in this field. It is a hard covered book, with very high production standards of text and illustrations. The name is rather a misnomer as an 'Introduction to Radiographic Cephalometry' — it is in fact a very detailed text, well suited to postgraduate students or clinicians involved in orthodontics or maxillo-facial surgery.

There is a very good introductory chapter on the reasons for cephalometric radiographs and then a detailed chapter on radiographic technique. I really liked the chapter on 'Tracing Techniques and Identification of Land Marks'. There are several templates at the rear of the book, plus a cephalogram. The reader is then taken, stage by stage, through the anatomical and then cephalometric landmarks. It is clear and easy to follow. The chapter on the Downes, Steiner and Ricketts analysis and the 'Wits' appraisal, and in fact the rest of the text book, are really of specialised interest to clinicians in orthodontics and maxillo-facial surgery. These chapters would be of less interest to readers in other fields. In a new text book on cephalometrics I would have liked to have seen a chapter on the computerisation of data from cephalograms. At the end of each chapter there are suggestions for further reading.

This book is a welcome addition to my bookcase and can be thoroughly recommended.

T. G. Leggat