Effects of deep and shallow water running on spinal shrinkage

C N Dowzer, T Reilly, N T Cable

Abstract

Objectives—Running in water has the potential to decrease the compressive forces on the spine as the body is supported. The aim of the study was to determine the magnitude of this loss in stature compared with running on land.

Methods—Fourteen runners completed three 30 minute runs on separate days in deep water, shallow water, and on a motor driven treadmill. During the three conditions, runners exercised at 90% of their exercise mode specific peak oxygen consumption. Subjects rested in the Fowler position for 20 minutes before and after exercise. Measurements of changes in stature were taken before resting, before running, after 15 minutes of running, after 30 minutes of running, and after the post-exercise rest in the Fowler position. Changes in stature were recorded using a stadiometer accurate to 0.01 mm.

Results—Loss of stature values were 4.59 (1.48), 5.51 (2.18), and 2.92 (1.7) mm (means (SD)) for running on the treadmill, and in shallow and deep water respectively. Running in deep water caused significantly lower creep than in the other trials (p<0.05), with no difference between the shallow water and treadmill conditions. Loss of stature was greater in the first half of the run for all conditions (p<0.05). Ratings of perceived exertion did not differ between the three exercise conditions.

Conclusion—Results support the use of deep water running for decreasing the compressive load on the spine.

Keywords: perceived exertion; spinal loading; stature; endurance running; water running

Endurance running places repetitive stress on the lower limbs and lower back. Compressive loading is inevitable during running as the feet impact with the ground 600–1200 times per km, with each foot strike inducing ground reaction forces equivalent to 2–4 times the body weight. This impact is attenuated by the training shoe or transmitted directly to the leg and spine, resulting in an increase in axial loading. When the compressive load exceeds the osmotic pressure of the discal tissues, fluid is expelled from the intervertebral discs. The resultant loss in disc height is referred to as spinal shrinkage.

The magnitude of shrinkage can be measured using precision stadiometry. This measuring technique has been validated by Boocock et al. Several authors have examined the effect of running on spinal loading. Garbutt et al reported significant differences in response to three running speeds, concluding that loss of stature increased as a function of exercise intensity. Greater loss in stature occurred during the first half of the 30 minute run than the second half, values being 3.26 (2.78) and 2.12 (1.61) mm respectively. This supports the observations of Reilly et al that the greatest loss in stature occurred in the early part of the run irrespective of the training mode (interval or continuous). This diminished response of the spine to compressive loading is due to a cumulative loss of fluid from the intervertebral discs. This rate of reduction in disc height is referred to as “creep”, with greater compressive loads accelerating the creep response.

The greater loss of stature in the early part of exercise may in part be explained by the exponential approach of Althoff et al, who devised a method of stature measurement that involved predicting the natural course of change in stature derived from observations during a pre-test period. The resultant change in stature during the test period was determined as the difference between predicted height and actual height during the test period. This technique eliminates the spinal loading history of individual subjects as well as accommodating the natural diurnal change in stature. However, this technique for determining spinal loading was deemed unsuitable for the present study as testing was carried out over a short duration and very small diurnal loss in stature would be balanced between the experimental conditions.

Running in water is a potentially useful therapeutic modality for runners with leg and back problems, since the body is supported. The added buoyancy has the potential to decrease the compressive forces on the spine which are evident during running on land. Deep water running is used by both injured and healthy athletes and appears to provide specificity of training for runners without incurring the potentially harmful effects of weight bearing exercise. Running in deep water with the aid of a flotation device allows the head to remain above the water and helps in maintenance of an upright position. An upright posture with the trunk perpendicular to the running surface is the ideal running position, allowing mobility of the pelvis and lumbar spine. This position is also the most efficient for ventilation. This is important as the chest is already under increased strain during deep
water running because of the hydrostatic pressure of the water on the thoracic cavity. Shallow water running involves running in water at waist height with the arms remaining above water. Town and Bradley found that shallow water running produced greater physiological responses than deep water running in terms of the higher oxygen consumption \( V_\text{O}_2 \) (90.3 and 73.5% of land values respectively) and heart rate (88.6 and 86% of land values respectively) attainable. Running in shallow water involves impact and incorporates a stance and push off phase of gait. Nevertheless shallow water running (and deep water running) alter the mechanics of running. In addition, the water resistance imposed on the body during aquatic locomotion is much greater than that on land, as water is about 800 times more dense than air. Furthermore, an additional resistance is generated by the water, with an increase in speed and surface area of the body.

The effects of running in water on the compressive load of the spine have yet to be investigated. The aims of this study were to compare changes in stature induced by running on land, and in deep and shallow water.

**Methods**

Fifteen male runners were recruited as a result of a questionnaire survey carried out on participants in endurance running events around the north west of England between March and May of 1995. Mean (SD) age, height, and mass for the group were 41.9 (9.1) years, 1.72 (0.07) m, and 68.4 (9.1) kg respectively. Written informed consent to participate was obtained from all subjects, and the study was approved by the institution’s human ethics committee.

Before measurement of the compressive loads on the spine, exercise intensity was determined in each of the three running media. This was established from maximal oxygen uptake tests carried out in each. Peak \( V_\text{O}_2 \) values from the maximal exercise tests were 55.39 (8.46), 45.94 (6.1), and 41.27 (6.37) ml/kg/min for treadmill, shallow water, and deep water running respectively (means (SD)). Exercise intensity for the spinal shrinkage study was set at 80% of mode specific peak \( V_\text{O}_2 \). Thus subjects were exercising at different absolute exercise intensities but the same relative intensity in each of the three running media.

The stadiometer used to measure changes in stature has previously been described by Boocock et al. A BBC microcomputer was used in combination with the apparatus to collect data. Before experimental testing, subjects were familiarised with the apparatus to improve reliability of subsequent experimental measurements. This also enabled the appropriate stadiometer settings to be established. A criterion of 10 consecutive measurements with a standard deviation of 0.5 mm or less was used to determine a subject’s ability to obtain reproducible measurements of stature. On average, 1.8 (0.6) training sessions were required in using the stadiometer. During training, 25.1
Table 1  Changes in stature during a 30 minute run on a treadmill, in deep and shallow water (mean (SD))

<table>
<thead>
<tr>
<th>Running conditions</th>
<th>Treadmill run (mm)</th>
<th>Shallow water run (mm)</th>
<th>Deep water run (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 20 min rest</td>
<td>+2.52 (1.85)</td>
<td>+4.07 (2.77)</td>
<td>+3.21 (1.65)</td>
</tr>
<tr>
<td>After first 15 min</td>
<td>-3.35 (1.48)*</td>
<td>-4.52 (2.15)*</td>
<td>-1.85 (1.48)</td>
</tr>
<tr>
<td>of running (80% max)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After second 15 min</td>
<td>-1.24 (0.99)</td>
<td>-0.98 (1.06)</td>
<td>-1.07 (0.93)</td>
</tr>
<tr>
<td>of running (80% max)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After 20 min recovery</td>
<td>+2.83 (1.23)</td>
<td>+3.89 (2.35)</td>
<td>+2.25 (1.53)</td>
</tr>
</tbody>
</table>

*p<0.05 difference in spinal shrinkage between first and second halves of the run. Negative sign indicates a loss in stature, positive sign indicates an increase in stature.

Figure 3  Mean losses (±SD) in stature as a result of 30 minutes of running on a treadmill (TMR), in shallow (SWR) and deep (DWR) water. *p<0.05 difference between deep water running and shallow water or treadmill running.

Results

Table 1 gives the effects of duration of the run on spinal shrinkage. The results show that duration of running has a significant effect on the shrinkage for the treadmill and shallow water conditions, with greatest shrinkage occurring in the first 15 minutes of each run (p<0.05). No significant difference in shrinkage occurred between the first and second halves of the deep water run (p>0.05). Figure 3 represents the shrinkage that occurred over the whole 30 minutes of running.

Running in deep water produced significantly less spinal shrinkage than either the treadmill or shallow water conditions (p<0.05), no difference being evident between the treadmill and shallow water running. None of the correlations between total shrinkage for the whole run and subsequent recovery during deep water running (r = 0.59), shallow water running (r = 0.50) and treadmill running (r = 0.07) reached significance.
Mean (SD) ratings of perceived exertion for the first 15 minutes of the run were 3.6 (1.7), 3.6 (1.7), and 3.7 (1.9) for treadmill, shallow water and deep water running respectively. Ratings for the second 15 minutes of the run were 3.7 (2.0), 3.5 (1.8), and 4 (1.9) respectively. All numbers corresponded to “moderately hard” on the scale. No differences for perceived exertion were recorded between any of the three running conditions or between the subjective measures recorded after 15 and 30 minutes of running.

Discussion
The exercise intensity in each of the experimental trials corresponded to a fixed percentage of the prevailing peak $V_{O2}$ established during maximal oxygen uptake tests in each training medium. As subjects were exercising at the same relative but not absolute exercise intensities for 30 minutes in the three running conditions, they were exercising at the same relative effort but at different absolute $V_{O2}$ values. This was reflected in the rating of perceived exertion, which did not differ between the three exercise conditions. The results for spinal shrinkage indicate that greater compressive forces were incurred during treadmill and shallow water running than in deep water running. In this study the exercise intensity was matched to the subject’s capability in the prevailing exercise, and so the relative metabolic strain (percentage of peak $V_{O2}$) was consistent between exercise modes. Nevertheless, the absolute $V_{O2}$ in the deep water compared with the other two conditions was lower and could be associated with a reduced load on the spine. Thus it is not conclusive whether spinal shrinkage values were totally dependent on the exercise mode or were influenced in part by the absolute $V_{O2}$ level. Further research is needed to determine whether metabolic responses per se affect the load on the spine. This could be achieved by assessing the stature changes associated with 30 minutes of treadmill running that elicit the same $V_{O2}$ as during deep water running.

Although losses of stature for the shallow water condition were not significantly greater than for the treadmill run, shrinkage was greatest for 12 of the 14 subjects in the shallow water run condition. The rotation movement of the upper body which was subjectively observed during shallow water running to maintain balance may have contributed to the greater amount of shrinkage in this running mode and needs to be investigated further, possibly by measuring muscle forces acting on the spine. No impact is made with the ground during deep water running. Thus it might be argued that the mechanism for inducing spinal shrinkage is absent. In the present study 30 minutes of running produced a loss of stature of 2.92 (1.7) mm. Dolan & Adams reported that the compressive loading due to body weight is about 380 N (59% of body weight) when standing still. As total compressive forces acting on the lumbar discs during standing are about 500 N, the remainder must come from the action of the back and abdominal muscles. The loss of stature that occurred during deep water running may be attributed to muscle tension in maintaining an upright posture in the water. Becker et al. reported that flexion of the thoracolumbar spine was evident, regardless of the type of flotation device worn by the subjects, a posture that is discouraged during running on land. Excessive forward flexion of the lumbar spine was noted during the present study, the pelvis being tilted anteriorly. This places greater strain on the muscles of the back to maintain posture. In addition, the muscles of the back (such as the psoas major) involved in flexion of the hip have been shown to exert considerable compressive forces, which increase from L1-L2 down to L5-S1. Thus, during the running action when the psoas major is helping to coordinate movement of the spine with the legs, loss of stature may be incurred.

Greater losses of stature were observed for the first half of the run than the second, supporting previous research. The values may in part be due to the previous unloading of the spine in the Fowler position. A recovery of disc height when in the Fowler position is a result of a reduction in the compressive loading of the spine and the subsequent rehydration of the intervertebral discs. Thus the potential of the spine to undergo compression is increased after a period of unloading. This could explain why spinal shrinkage values were greater during the first half of the run than in the second half when creep effects within the discs are less responsive than before.

Several authors have examined the in vitro response of the intervertebral discs, showing that the discs respond in a viscoelastic manner. During periods of extended loading, the rate of reduction in disc height is nonlinear, with the greatest loss occurring in the early stages of loading. The implication is that the discs are stiffer in the later parts of prolonged exercise and as a result less responsive to impact loading. The stadiometer used in the present study controlled for changes in spinal curvature that may be associated with changes in stature. Articular cartilage deformations and flattening of the arches of the feet are potential sources for changes in stature. However, the magnitudes probably do not account for the changes observed in the present study.

In conclusion, this study showed that loss of stature was greater during treadmill and shallow water running than during deep water running. The rate of shrinkage decreased as the run progressed, which supports other results in the literature. The present study is the first of its kind to examine spinal shrinkage during aqua-running and supports the use of deep water running for reducing the compressive load on the spine in both injured and uninjured runners. Analysis of spinal flexion during land and water running would provide a greater understanding of the loads being placed on the spine. This could be carried out with the use of a waterproof goniometer placed vertically along the spine. The findings of the present...
study clearly show that running in deep water markedly decreases spinal loading.