THE RACE DOWN FROM EVEREST: Impact Absorption in Extended Downhill Running

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INTRODUCTION

At 7:04 a.m. on November 27,1987 forty five runners from eight countries started the world's highest marathon. The Everest Marathon began at Gorak Shep (at an altitude of 5184 metres, just below the Everest Base Camp), and finished at Namche Bazaar (altitude 3446 m). In addition to being the world's highest marathon, it also involved the most downhill running. Total descent was approximately 2138 m, including the effect of two major uphill portions (see Figure 1). Competitors trekked into Namche Bazaar, and then on to Gorak Shep over a 2.5 week period. This allowed enough time for acclimatisation, and for them to become acquainted with the course.

The Everest Marathon was held for several reasons. Apart from providing a spectacular athletic event, the organisers raised money for charities working in Nepal, and promoted awareness of conservation problems in the Sagarmatha (Everest) National Park. It also provided a unique opportunity for biomechanical and physiological research.

The race was run on mountain trails, which frequently provided uncertain footing due to loose rocks and gravel. In addition, runners had to contend with the normal traffic on the trails (including yak trains), as it was impossible to clear the route for the race. Contrary to many opinions expressed before the race, no serious injuries were sustained. Forty two runners finished the race, and three stopped after completing 32.2 km. Although several competitors had previously recorded sub-2:30:00 marathon times, the race was won in 4:53:10, and only nine runners finished in under six hours.

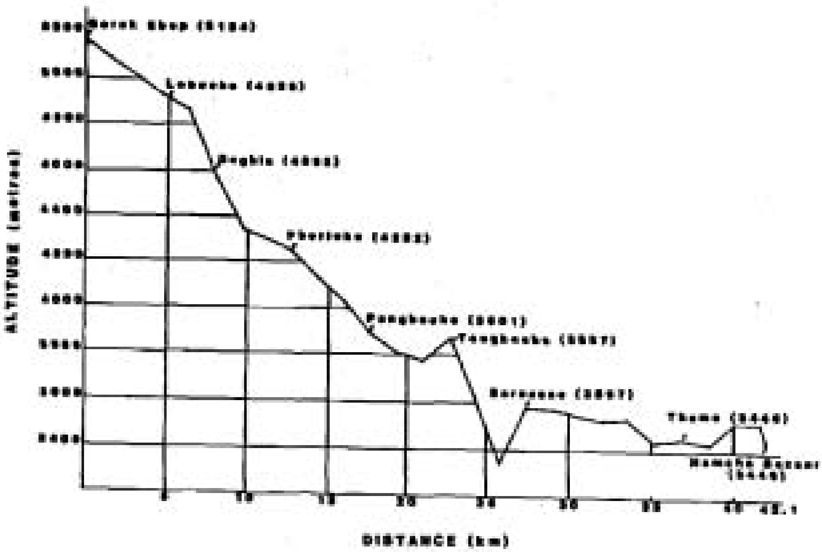

Figure 1: 1987 Everest Marathon Altitude by Distance

Preparations for the race by the organisers were necessarily thorough and intensive. One of the major concerns was that runners might develop high altitude pulmonary oedema (mountain sickness). Eight doctors accompanied the runners during the trek in, and in conjunction with two docfors in the region set up ten well-equipped medical posts along the race route. Runners were advised of the benefits of acetazolamide (Diamox), a drug which has been shown to enhance acclimatisation to altitude, and it was available under supervision from the doctors in the group. Virtually all the runners used the drug, and only a few cases of mild mountain sickness were recorded.

One of the main interests in the race from a biomechanical point of view was the opportunity to study the runners' adaptation(s) to the effects of such a long period of downhill running. Specifically, we were interested in their responses to the problem of energy absorption at impact, and the effects of prolonged eccentric work by the knee extensors.

RELATED LITERATURE

Newham (1988) has recently reviewed the general literature on eccentric muscle actions and their relationship to delayed on set muscle pain. He notes that the pain is particularly associated with unfamiliar and high force muscle work, and that the pain is usually noticed after about eight hours, and is maximal 24 to 48 hours later. With specific reference to running, Dick and Cavanagh (1987) reported high levels of muscle soreness 24 to 48 hours after 40 minute downhill run on a -10% grade.

Running on the level involves eccentric action of the knee extensors for a short period after impact. This occurs while the quadriceps are activated, but the knee joint is flexing. Buczek and Cavanagh (1987) found maximum knee flexion to average 0.77 radians (44 degrees) and occur at 34% of the stance phase. They contrasted this to running on a -10% slope, where a greater and later maximum knee flexion was seen (0.84 radians, 41% of stance). In both of these situations, the knee joint typically flexes on impact, and then extends for the remainder of stance. Buczek and Cavanagh also reported knee angles at impact for level and negative slope running, and found a decrease in average knee angle at impact from 0.44 radians to 0.30 radians for downhill running.

A qualitative analysis of running, such as that outlined by Hay and Reid (1982, pp. 310) allows evaluation of running style. A model of this sort should also permit an assessment of the effects of external variables on the significant mechanical factors involved. Thus, one might predict the changes most likely to occur as a result of altering the slope of the terrain. Changes found in running downhill are likely to be in body position at foot strike and toe-off, and in the different height of take off and landing. All three of these factors affect stride length, and only one (relative height at toe-off) affects stride frequency. One would expect, therefore, to see more noticeable changes in stride/step length than stride/step frequency during downhill running.

Another factor expected in running on a negative slope would be increased energy absorption demands being placed on the body at impact with the ground. This could be catered for by those joints normally associated with negative work at heel strike, namely the ankle and knee joints. There are at least two possible approaches to altering the energy absorption potential of a joint: change the joint angle at impact to permit a greater range of movement over which to perform negative work; or increase the stiffness of the eccentrically acting muscles. Thus we might expect to see either changes to the ankle and knee joint angles at heel strike, or enhanced electromyographic activity of the eccentric muscles prior to heel strike.

Another method which could be used by runners to reduce energy absorption requirements would be to decrease step length and increase step frequency. This would reduce the vertical kinetic energy of the runner at impact, yet maintain their speed.

METHODS

Approximately 25 experienced marathon runners were filmed at the 25 and 41 kilometre points in the marathon (the villages of Tengboche and Namche Bazaar respectively). Camera speeds, track slopes and linear scaling factors were calculated, and leg length, step lengths, step frequencies, knee angles at impact, and angles of maximum knee flexion were determined for each runner who appeared in both films (N=20). Data from runners who wore baggy leg coverings or who did not run on the track were excluded from the step length and angular data analysis. Normalisation of step lengths and average velocities was performed in order to remove the effects of subject anthropometry. Step lengths were normalised to the runner's ankle to hip length to facilitate inter-subject comparisons. Normalised average speed was calculated from the product of normalised step length and step frequency. Data were averaged for each subject, and the change in each variable between the two filming points calculated.

RESULTS

The slope of the track at Tengboche was -0.21 rad (-21.8%). Table 1 shows the group means and standard deviations for the temporal, and speed and angular data collected. Normalised step length did not change between Tengboche and Namche Bazaar, but significant differences were seen in step frequency and normalised speed. Thus runners averaged a greater number of steps per second and were running faster at the second testing site. The absolute values of the runners' averaged step lengths were calculated to facilitate comparison with published data, and they were 0.94 m and 0.96 m respectively for Tengboche and Namche Bazaar.

No difference was seen in either knee angle at impact or maximum knee angle during stance between the two filming sites. However, seventeen of the twenty subjects recorded their maximum knee angle at toe-off (100% of stance).

Although the runners were not specifically canvassed after the race about muscle soreness, not one case of severe muscle pain was reported, and the general comment was that they felt no more sore than after any other marathon.

DISCUSSION

In spite of participating in an activity involving prolonged repetitive eccentric muscle actions, this group reported no cases of severe muscle soreness 24 to 48 hours after the race. There are several possible explanations for this result.

Some work has suggested that muscles are able to accommodate to repeated bouts of eccentric work, and subsequent severe muscle pain is reduced significantly. During the 2 1/2 week trek in to the race start, the athletes were forced to include a considerable amount of eccentric exercise in their daily runs. Although of relatively short duration, these training activities may have reduced post-race muscle pain.

Our biomechanical results indicate the runners employed a number of techniques to minimise the magnitude of the impact shock, and to reduce the magnitude of the forces required at the knee joint. First of all, the absolute values for average step lengths were slightly shorter (0.94 m and 0.96 m respectively vs 1.1 m) than those reported for level running at 3.0 m s^{-1} (Luhtanen and Komi, 1978). Expressed as a proportion of leg length, they were shorter than the values reported by Roy (1982) for distance runners (1.07 and 1.09 vs 1.50), and for downhill running (Nelson and Osterhoudt, 1971; Dick and Cavanagh, 1987a), although in both of those studies the runners' speeds were greater. Their step frequencies appear to be normal for their speed.

TABLE 1: Group means and standard deviations (in parentheses) for temporal, speed and angular data

	Tengboche	Namche Bazaar
Normalised step length	1.07 (0.15)	1.09 (0.25)
Step frequency* (/s)	2.38 (0.18)	2.97 (0.24)
Normalised speed*	2.56 (0.43)	3.91 (0.62)
Impact knee angle (rad)	0.21 (0.06)	0.21 (0.05)
Maximum knee angle (rad)	0.90 (0.12)	0.95 (0.14)

* significant at $p < 0.01$

From this, it appears the runners attempted to limit their kinetic energy at impact on these steeper slopes by increasing step frequency and maintaining a relatively constant and moderately short step length. These changes would have the effect of preventing the vertical component of the impact energy from increasing significantly by reducing the vertical drop of the body.

On average, the runners' stance leg impacted the ground with a more extended knee, and achieved a greater maximum knee flexion in stance when compared to either level or -10% slope running. It would appear the runners attempted to provide a greater range of movement at the knee joint over which the eccentric work would be done. This could permit lower forces to be generated while producing the same net impulse.

The majority of the runners did not have a stance knee extension phase when running past the filming sites. This implies the quadriceps muscle activity was primarily eccentric and suggests one of the factors in producing micro-trauma in the muscle may be the change from eccentric to concentric muscle activity in a movement.

Another unique aspect of this race was the runners' use of acetazolamide to aid acclimatisation. A side effect of this drug may be to reduce the effects of eccentric muscle activity, although if the major cause of muscle pain is physical damage to muscle fibres and membranes, this is unlikely to be a factor. However, the drug may have an effect on mononuclear cell infiltration or subsequent intramuscular pressure, both of which have been suggested to play a role in the pain.

SUMMARY

This work has provided a description of some of the biomechanical variables which change with prolonged downhill running. Runners appear to manipulate their step length and frequency to maintain or minimise their kinetic energy at heelstrike. They also vary their knee angle at impact and the total amount of flexion at the knee to provide a greater range of motion over which to do the eccentric work required. Both of the above factors would lend to reduce the magnitude of the muscle forces produced by the knee extensors. The majority of runners also eliminated any knee extension during stance while running on these steep slopes. These and other factors may have interacted to limit the incidence and severity of post-race muscle pain.

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