Exercise and altitude

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Summary

In studies concerned with the performance at high altitude it is often not possible to separate the effects which are due to hypoxia from those associated with the stress of ascent. Some of the basic observations concerning exercise at high altitude are reviewed and a study is described which was designed to simulate the physical exertion of high altitude mountaineering but performed at altitudes below 1000 m. Some of the changes observed including peripheral oedema might under other circumstances have been ascribed to altitude.

Introduction

It is more than a hundred years since observations were first carefully recorded on the effects of hypoxia on the ability of the human subject to undertake physical exercise at high altitude. A great impetus was given to such studies by the establishment in the 1890s of high altitude laboratories. From this time the effects of hypoxia and the influence of hypoxia upon ability to work formed a significant part of human physiological research. More recently attention has also been directed to the physiological changes which occur in response to exercise carried on under hypoxic conditions.

Two strands of development can be discerned: one uses studies at high altitude as a means of elucidating fundamental physiological processes, e.g. the work of Barcroft (1925). The other strand has the aim of providing practical solutions to problems such as how best mountaineers can be selected for climbing the highest peaks (Keys *et al.*, 1938), or how best athletes can be trained for competition at a higher altitude than that to which they are accustomed. The preparation for the 1968 Olympic Games held at a height of 2400 m directed considerable effort to this end (Jokl and Jokl, 1968).

These 2 strands of research interest are often intertwined and it is common for results to be interpreted with reference to the hypoxic element alone when it is clear from the experimental protocol that they may have been influenced to an unknown degree by the exercise taken during exposure to hypoxic conditions. It is easy to exclude exercise when the work is confined to a decompression

chamber but experiments have to be very carefully designed when the study demands actual ascent to, and a protracted stay at, high altitude.

Many of the basic observations concerning exercise at high altitude are now established. For example, at altitudes of about 2000 m contests requiring short bursts of energy expenditure yield slightly better results than at sea level. In contrast, contests depending on endurance yield, on the average, poorer results. This finding applies also to such animals for which comparable data are available, the most detailed records being of the performance of racehorses at different altitudes.

One of the earliest experiments to establish the decrease in endurance working capacity at altitude was that of Whympers (1892). He laid out a measured level half mile and timed himself at each mile while walking to and fro over it for 6 successive miles. When he compared the result obtained at 3100 m with that obtained using a similar procedure at about sea level he found that he averaged 54 seconds longer per mile at high altitude.

What underlies the poorer endurance performance? The symposium held in Milan in 1966 examined many relevant problems (Margaria, 1967) but at that time conflicting results were being obtained. Alexander *et al.* (1967) showed that, at rest and at each level of exercise studied, the cardiac output was less at 3100 m than at sea level by as much as 2 litres/min due chiefly to decreased stroke volume while Stenberg, Ekblom and Messin (1966) found that when man is exposed to acute hypoxia his cardiac output at any given submaximal work load is increased.

The present author, as well as many others, has shown that an increased heart rate is recorded immediately on arrival at high altitude and it decreases slowly thereafter. It is also agreed that for a given level of exercise the cardiac output is greater at high altitude than at sea level but returns towards the sea level value after a period of some weeks (Vogel, Hansen and Harris, 1967). There is still a lack of data on the time course of this return to values similar to those obtained at sea level but a wide individual variation is likely.

Although much light has thus been shed on the

effect of altitude on athletic performance and also on acclimatization to altitude little work has been done on the physiological changes which occur when moderately severe exercise is undertaken on successive days at altitude. This is of little relevance to competitive sport but is of importance to mountaineering for 2 reasons. The first is that many mountaineers make arduous ascents when at altitudes to which they are only partially acclimatized and the second is that frequently such exercise extends over several days.

Exercise and acute mountain sickness

Many anecdotes suggest a correlation between the severity of acute mountain sickness (AMS) and the degree of exercise taken at altitude shortly before its onset. Perhaps the first well documented example is that of Dr Jacottet who spent 2 days at 4300 m on Mont Blanc then went to the summit (4800 m), later returning to 4300 m. During the succeeding night AMS set in and he died in less than 24 hr. Mosso (1898), in commenting on the post-mortem report, states that "the more immediate cause of death was therefore probably a suffocative catarrh accompanied by acute oedema of the lung". More than half a century was to elapse before it became commonly recognized that oedema was the pathological condition underlying the various manifestations of AMS.

Evidence now suggests (Editorial, 1976) that the incidence of clinically evident AMS is directly related to the degree of exercise taken at high altitude in the period preceding the onset of symptoms. It thus seemed desirable to arrange a protocol which was the inverse of that often followed by the author in field studies of hypoxia. Exercise should be taken of the type and duration typical of mountaineering but over mountains of altitude well below that at which AMS occurs.

In the winter of 1976 M. P. Ward and the author carried out a preliminary study in the mountains of North Wales. Energy was expended at the rate of 20 000 to 24 000 kJ/day for 4 consecutive days and towards the end of this period peripheral oedema was detectable. A water-balance study demonstrated a water retention during the exercise followed by a diuresis. In one subject this began before the end of the period and in the other after exercise had ceased.

As this was a preliminary experiment the water balance was not carried out with all possible refinements and certain concomitant observations were not made. In view of the encouraging results a more precise experiment was carried out in North Wales in the winter of 1977.

Five male subjects whose work was semi-sedentary, who were not in training but who were in the habit of occasionally taking exercise of the endurance

FIG. 1. Pitting oedema in one subject following 7 successive days' hillwalking. The subject was then, and has remained since, completely healthy.

type, were studied over a period of 13 consecutive days. Three of the 5 subjects had had considerable experience between 4000 and 6000 m and one had spent time at over 7000 m.

The experimental period was divided into 3 parts: a control period of 3 days with an estimated energy expenditure of 10 000 kJ/day; an exercise period of 7 days with an estimated energy expenditure of 17 500 kJ/day; and a recovery period of 3 days under the same conditions as the control period. The exercise period was planned to simulate alpine climbing, i.e. the conditions which, when the subjects are hypoxic, apparently produce an increased incidence of AMS. Under the conditions of the experiment there was, of course, no hypoxic stress.

The results are published elsewhere (Williams *et al.*, 1979). Water retention was demonstrated but the findings could best be explained by a movement of water from the intracellular space to the extracellular space in addition to the water retention. That there was excess interstitial fluid was demonstrated by the presence of facial and lower leg oedema. This varied on clinical examination from equivocal to obvious. The most marked example of oedema is illustrated in Fig. 1.

Discussion

While there is still scope for further work relating to athletic performance at moderate altitudes and especially to the time-course of acclimatization for athletic competition at such altitudes it would appear that a fruitful field for further research is related to protracted exercise. Not only has little been done at high altitude but also surprisingly little under conditions where there is no oxygen lack.

In the work to which brief reference has been made (Williams *et al.*, 1979) the authors considered that an increase in the capacity of the vascular space with exercise, presumably that of the working muscles, may underlie the increase in the plasma volume found. This could be mediated either by hormonal response to a reduced pressure in the great veins or by small changes in capillary pressure moving the net flux of water slightly in favour of

inward movement to the blood vessels. This would account for the plasma volume being disproportionately increased compared with the interstitial fluid volume. The explanation for the shift of fluid from intra- to extracellular spaces remains obscure.

The increase in extracellular fluid indicated by this study would explain the dependent and peri-orbital oedema often noted in the early days of an active holiday. It would also give support to the impression that there is an association between the taking of exercise on arrival at high altitude and the incidence of AMS and between the degree of exercise and the severity of AMS.

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