Effects of cooling the legs on performance in a standard Wingate anaerobic power test

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The possibility that peripheral hypothermia may impair muscular performance in various sports led us to assess the usefulness of the Wingate anaerobic power test in subjects with normal and cooled leg muscles. Using this test without modification, peak power, average power output, and cumulated work to the point of fatigue were all decreased by cooling, although the fatigue index (the declining rate of change of power output) was less. It is concluded that this test could usefully be employed in field studies to assess the possibility that muscle chilling may influence a person's potential for producing maximal bursts of muscular work.

Keywords: Muscle fatigue, muscle temperature, power output, supramaximal exercise, dynamic exercise

As it is well known that extremes of both hypothermia and hyperthermia impair muscle function, it is evident that there must be an optimal temperature range within which the best performance of muscle may be obtained. To maximize short-term power output in the major limb muscles, the temperature required appears to be slightly higher than that found in resting muscle in a thermoneutral environment. However, the physiological mechanisms of homeothermy are unable to keep limb muscle temperature close to the optimal range even in moderately cold conditions. Although the body core temperature can be relatively well protected, if the whole body is exposed to cold, the more peripheral parts (i.e. the limbs) cool quite quickly. Cold immersion in water is of special interest due to the relatively high rate of heat loss compared with that in air, although there are circumstances in which a degree of cold exposure may affect power generation in sports on land. General hypothermia poses its own problems, but the more common peripheral hypothermia is the subject of this study.

When considering the effect of temperature on muscle function, power output and fatigue, it is necessary to look beyond the effects of temperature on the contractile process. Limb cooling might affect power production at one or more of the several steps from volition to power output itself (Figure 1). Central causes of reduced power output or fatigue might include motivation, impairment of transmission down the spinal tracts, and impaired recruitment of motor neurons, while peripheral causes might include impairment of transmission in the peripheral nerves, of neuromuscular junction transmission, of intramuscular transmission, and of activation of contraction. At several of these points the primary problems might be due to 'upstream' or 'downstream' effects on substrate supply or waste product removal, by the influence of temperature on either transport or metabolism. In vitro studies, or isolated muscle studies of power generation at controlled temperatures, despite having much intrinsic interest in themselves, cannot substitute for trials in the whole man if one is interested in studying the practical problems of maximizing performance in those who participate in sports in potentially cold environments (e.g. swimmers, water polo players, rock climbers, or goalkeepers in association football).

We decided to assess the suitability of a standard power test for performance at the poolside, or in other situations where hypothermia of the limbs is present.

![Diagram](image_url)

**Figure 1.** Command chain for muscular contraction (Redrawn after Gibson and Edwards and reproduced from Reference 7 with permission from the publisher)
might reduce power generation either acutely (peak power output) or by reducing the work capacity to the point of fatigue (anaerobic capacity). In our study, performance using the lower limbs before and after cooling was determined using the Wingate anaerobic test. Peak power and anaerobic capacity were compared under these particular test conditions when the subject had been exposed previously either to normal room temperature conditions or to 30 min of leg-cooling, induced by sitting up to the waist in a water tank at 12°C. The effect of cooling followed by rewarming on performance in a subsequent Wingate test was also studied.

Methods

Three male subjects aged 20–21 years participated in the study. In all experiments a standard anaerobic test (the Wingate test) was performed. The test requires pedalling a mechanically braked Monark cycle ergometer with maximal effort for 30 s. The braking force to be applied for two subjects of average fitness was 80 g/kg, and for the third (less fit) subject was 71 g/kg. Rate of movement of the flywheel was measured using a light-sensitive monitor interfaced to an Acorn BBC Master computer. The primary calculations were performed by a program supplied by Cranlea, Birmingham, UK.

All subjects were thoroughly familiar with the apparatus and procedures before the test measurements were made. On control days the subject performed the test with no prior warm-up period. A total of six control experiments were performed on each subject, but no more than two control experiments at room temperature were carried out on any one day.

To cool the lower limbs the subject was seated up to waist level in a tank of circulating cooled water at a temperature of 11.5–12.2°C for 30 min. The following temperatures were measured at 5-min intervals; room and tank temperatures (mercury thermometer), aural temperature (zero gradient thermometer), rectal temperature, and thigh and calf skin temperatures (thermistors). Heat flow through the thigh was measured using heat flow discs containing thermocouples.

Two post-cooling tests were performed on each subject on successive days. The Wingate test was performed immediately after emerging from the cold water and after putting on training shoes. Following the test the subject was rewarmed in a hot bath at a temperature of 42–44°C. Once the aural and rectal temperatures had started to rise steadily, usually after about 20 min, the subject left the bath. On one occasion for each subject a further Wingate test was performed following rewarming in the bath.

Results

Temperatures and heat flow

The values for aural and rectal temperatures and for heat flow across the thigh for the 30-min cold immersion period are illustrated for one subject in

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Figures 2 and 3. Both rectal and aural temperatures initially fell on immersion due to the return of cooled blood from the periphery. In the core (aural thermistor probe) this fall may be halted or even reversed after about 10 min due to thermoregulatory mechanisms producing peripheral vasoconstriction and thus protecting the core, as in the example shown in Figure 2. If the cold is sufficiently severe and prolonged, there would eventually be a persistent drop in core temperature as these protective mechanisms cannot fully compensate for the rate of heat loss.

In the experiment illustrated, while aural temperature remained close to its original value during the 30-min cooling period, cold blood returning from the cooling legs depressed the rectal temperature continually. Thigh and calf skin temperatures (not illustrated) showed an abrupt and rapid drop on immersion, followed by a very gradual decline. Heat flow across the skin of the thigh (Figure 3) rapidly increased on immersion due to the conductive

Figure 2. Changes in aural (——) and rectal (——) temperature observed during and after immersion up to the waist for 30 min at 11.5°C, and followed by spot records of these temperatures before and after the standard Wingate anaerobic test

Figure 3. Heat flow through the skin after leg muscle cooling
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properties of water and then, as the leg cooled, gradually declined over the 30-min period to a value about half of that seen immediately after immersion.

Power output

Analysis of the results (Table 1) using the Student’s t test for paired data showed that, with cooled limbs, the average power output and hence the cumulated work during the Wingate test fell by about 26% ($P<0.02$). Peak power was also reduced by 30%. These changes should be considered in relation to a mean intra-subject coefficient of variation of 2.4% for average power output, 4.3% for peak power during six repeated tests in the normal, warm condition. Although this was not based on any deliberate temperature equilibration procedure as, for example, sitting in a warm bath, the Wingate test in the normal warm subject was therefore quite closely reproducible. In every case, the result with cooled legs was far outside the 95% range of normal warm values for that individual. Figure 4 shows typical results from one subject. Following rewarming, the average power output for the Wingate test in each subject was not significantly different from control.

![Graph](image)

**Figure 4.** Wingate test with the legs warm (□) and cooled (●) (data for one subject)

Fatigue index

The values of the fatigue index are also shown in Table 1. For each subject, when working with cooled legs, the rate of decline of power output on both occasions was outside the 95% range covered by values recorded in the six tests performed while warm. In other words, having reached a lower peak power, the cooled muscles were losing power less quickly. Nonetheless, cooled muscles were unable to perform as much cumulated work during the exhausting 30-s test period as they could when warm.

Discussion

The results of this investigation have shown that using the defined conditions of a standard Wingate anaerobic test, power output from cooled legs muscles was reduced by a quarter. It was also found that the fatigue index (expressed as change in power output/s) declined on cooling the lower limbs. The direction of the first of these changes is in agreement with the results of a number of other authors who have reported decreases in maximal dynamic strength and power output. It also matched changes of indices of contractility which imply a slowing of muscle contraction at low muscle temperatures under a variety of experimental conditions. There is great diversity in the literature over the effects of cooling on indices of fatigue using tests of differing duration and intensity with either isometric or dynamic work.

Muscle temperature was not measured during the present series of experiments, partly because this is an invasive procedure needing special precautions and partly because the value of a spot measurement would be limited in relation to the effort and risk involved. There is a wide range of temperature in the extensive muscle mass involved in the supramaximal cycling work performed, ranging from arm, shoulder and back muscles to foot muscles. Surface temperature over the cooled quadriceps muscles was measured as 12–15°C, and muscle temperature in the leg is estimated to have been about 29°C by analogy with the results of Blomstrand et al. who used a very similar cooling protocol.

In conclusion, the study presented here shows that the standard Wingate test can be used to demonstrate the importance of muscle temperature to perform-

<table>
<thead>
<tr>
<th>Subject no.</th>
<th>Average power (W/kg)</th>
<th>Peak power (W)</th>
<th>Fatigue index (Wis)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control ($n = 6$)</td>
<td>After cold (2 trials)</td>
<td>Difference (2 trials)</td>
</tr>
<tr>
<td>1</td>
<td>9.42(0.18)</td>
<td>7.37</td>
<td>2.05</td>
</tr>
<tr>
<td>2</td>
<td>8.69(0.23)</td>
<td>5.88</td>
<td>2.81</td>
</tr>
<tr>
<td>3</td>
<td>10.19(0.29)</td>
<td>7.71</td>
<td>2.48</td>
</tr>
</tbody>
</table>

*Values are mean(s.d.)*

ance in sprinting exercise. As in other studies of the effect of cooling on dynamic exercise, the decrement in performance seems to be of the order of 4% per °C change in muscle temperature. The effect is sufficiently marked that this simple test might be useful in field studies of the power outputs that can be achieved by those athletes who are at risk of peripheral hypothermia while waiting their turn to participate actively in their sport.

References


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