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Effects of Prolonged Warm-up Exercise Above and Below Anaerobic Threshold on Maximal Performance*

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Summary. The purpose of the present study was to determine the effects of prolonged warm-up exercise above and below anaerobic threshold (AT) on maximal performance. Warm-up exercise consisted of pedalling the Monark cycle ergometer at either 40% (Below AT) or 68% (Above AT) of $\dot{V}O_2$ max for 60 min. Each maximal performance consisted of two 40 s bouts of "all out" pedalling on the Monark cycle ergometer against 5.5 kg resistance separated by a 5 min rest period. These tests were administered on two occasions without warm-up exercise and were found to be reproducible for work output and peak blood lactate concentration. Below AT warm-up exercise significantly increased core temperature with no increase in steady state blood lactate concentration and was thus representative of a desired warmed-up status. This condition did not contribute to an improved maximal performance. Above AT warm-up exercise resulted in significant increases in core temperature and steady state blood lactate concentration. Work output and peak blood lactate concentration for maximal exercise were significantly decreased. It was concluded that task specific prolonged warm-up exercise below AT does not contribute to an improved maximal performance of the type employed in the present study. Following warm-up exercise above AT, maximal performance was impaired. This was attributed to probable glycogen depletion in fast twitch muscle fibers which in turn may have contributed to a decreased lactate production.

Key words: Cycle ergometer – Blood lactate – Core temperature

Warm-up exercise prior to maximal performance represents a generally accepted practice among athletes. Although universally accepted as an aid to performance, this procedure is essentially unsubstantiated. Previous studies

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Table 1. Physical characteristics of subjects (Mean ± SEM)

Age (years)	Height (cm)	Weight (kg)	$\dot{V}O_2$ max (ml · min^{-1})	$\dot{V}O_2$ max (ml/kg · min^{-1})
23.4 ± 1.9	178.7 ± 2.9	78.5 ± 4.9	3,701 ± 203	48.1 ± 4.8

have provided conflicting research results which are difficult to interpret. Several studies suggest a favorable effect derived from warm-up exercise (Asmussen and Boje 1960; Martin et al. 1975; Ingjer and Stromme 1979; DeBruyn-Prevost 1980) while others report no effects (Knowlton et al. 1978; Sedgewick 1964; Sedgewick and Whalen 1964).

Differences in method among studies may help explain conflicting conclusions. Although Burke (1957) suggests the importance of careful manipulation of intensity and duration of warm-up exercise, core temperature and/or muscle temperature have not been systematically increased. For example, low level and/or short duration warm-up exercise may not increase core temperature and it has been suggested that warm-up exercise resulting in an increased core temperature of at least 0.6° C is desirable (deVries 1980). On the other hand, intensive warm-up exercise may lead to fatigue of unknown causation. Results from several investigations suggest that elevated blood lactate concentration associated with prior exercise may contribute to fatigue (Klausen et al. 1972; Karlsson et al. 1975). Other studies indicate that elevated blood lactate concentration prior to maximal exercise does not impair performance (Weltman et al. 1977; Weltman et al. 1979).

The present study investigated the effects of prolonged warm-up exercise below (40% of $\dot{V}O_2$ max) and above (68% of $\dot{V}O_2$ max) anaerobic threshold (AT) on maximal performance.

Methods

Physical characteristics of five male volunteer subjects are reported in Table 1. All subjects regularly participated in various physical activities but none was highly trained nor involved in cycling on a regular basis. Although informed of their role and all potential dangers prior to signing a detailed consent form, subjects were unaware of the purposes of the study. Prior to participation each subject passed a medical examination by a cardiologist.

Each subject completed six tests. The first was a discontinuous cycle ergometer maximal oxygen uptake ($\dot{V}O_2$ max) test consisting of 3 min work bouts alternated with 5 min rest periods. The test was initiated at 30 W and increased 30 W each successive load until the subject could not complete a given work level. A plateau or drop off in $\dot{V}O_2$ with increasing work load was evidence that $\dot{V}O_2$ max had been achieved (Taylor et al. 1955). Open circuit spirometry methods were utilized for determination of $\dot{V}O_2$. Expired gas was collected in meterological balloons and its volume measured using a Tissot gasometer. Concentrations of O_2 and CO_2 were determined with a paramagnetic O_2 analyzer (Applied Electrochemistry S-3A) and an infrared CO_2 analyzer (Beckman LB-2). Core (rectal) temperature was measured using a digital thermocouple thermometer (Baily TVC) and heart rate was counted from electrocardiograms. Blood samples were obtained from an antecubital vein at regular intervals and analyzed for blood lactate concentration by enzymatic analysis (Gutmann

1974). To ensure a sizeable difference in blood lactate concentration between above and below AT work levels while at the same time permitting a full 60 min exercise period without exhaustion in moderately trained subjects, the work level eliciting a 4 mM steady state blood lactate concentration was chosen for above AT exercise. Pilot data had revealed that a 4 mM concentration in agreement with the concept of "Onset of Blood Lactate Accumulation" (OBLA) (Sjodin and Jacobs 1981) was ideal.

The second test entailed 20 min of exercise at the below AT work level to ensure that steady state blood lactate concentration was not elevated above resting levels. Following a 20 min rest period another 20 min exercise period at the above AT work level was conducted to ensure that steady state blood lactate concentration approximated 4 mM. Adjustments in work level were made when necessary to validate these responses prior to implementation of the remaining tests.

The four remaining tests were randomly assigned.

1. Maximal Test I. This test required completing as many pedal revolutions as possible in 40 s on a Monark cycle ergometer. Resistance was set at 5.5 kg within 2 s of the command "go" and pedal revolutions were recorded from a microswitch recorder assembly. Total work output was computed with respect to resistance and completed pedal revolutions and reported in watts. Following a 5 min rest in which subjects were permitted to walk about freely, the test was repeated. Pilot data had revealed that following two such maximal tests separated by 5 min, the blood lactate concentration was significantly higher than after one. The level was not further significantly raised following three tests and work output decreased markedly on the third attempt. It was concluded that two successive 40 s maximal tests separated by 5 min provided the potential for reproducible work output and significant increases in blood lactate concentration. A blood sample was obtained 5 min after completion of the second test and analyzed for blood lactate concentration.

2. Maximal Test II. This test was identical to Maximal test I and was conducted for the purpose of testing reproducibility.

3. Below AT. This test consisted of pedalling the cycle ergometer at a work rate approximating 40% of $\dot{V}O_2$ max for 60 min. A 10 min rest period was allowed followed by the identical maximal test described above. The 10 min rest period permitted ventilation to decrease toward resting levels and also permitted psychological preparation for the maximal test. During exercise at 40% of $\dot{V}O_2$ max, blood samples were obtained at 5, 20, 30, 45, and 60 min and core temperature was monitored throughout.

4. Above AT. This test was similar to the Below AT with the exception that the work rate for the 60 min period was increased to approximately 68% of $\dot{V}O_2$ max.

Statistical procedures applied to post maximal exercise blood lactate concentration and total work output entailed a repeated measures one way analysis of variance. Differences between Above AT and Below AT steady state exercise with respect to blood lactate concentration and rectal temperature were determined with a multifactor ($5 \times 5 \times 2$; subjects, time, conditions) completely within subjects analysis of variance with repeated measures on subjects and time. A student Newman-Keuls post hoc test was performed when statistical significance was found at the 0.05 level.

Results

The two maximal tests (I and II) were found to be reproducible according to the following criteria: (1) there were no significant differences between tests for either work output or blood lactate concentration; (2) the absolute mean differences for work output and blood lactate concentration were 10.5 ± 5.5 W and 1.1 ± 0.08 mM, respectively; and (3) the correlation coefficients (r) for work output and blood lactate concentration were +0.88 and +0.91, respectively ($p < 0.01$).

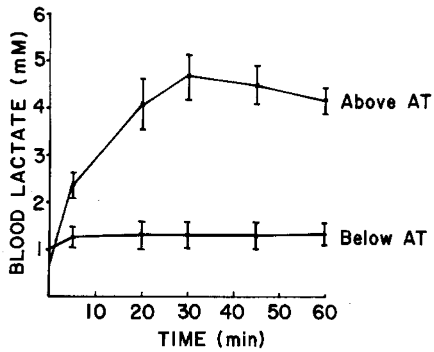

Fig. 1. Blood lactate concentration (Mean ± SEM) during 60 min of exercise below (40% of $\dot{V}O_2$ max) and above (68% of $\dot{V}O_2$ max) anaerobic threshold

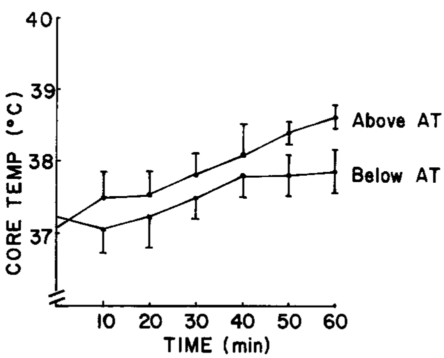

Fig. 2. Core (rectal) temperature (Mean ± SEM) during 60 min of exercise below (40% of $\dot{V}O_2$ max) and above (68% of $\dot{V}O_2$ max) anaerobic threshold

Table 2. Peak blood lactate and total work output

Test	Work output (W) (sum of two 40 s tests)	Peak Blood Lactate (mM)
I	706.2 ± 26.4	11.5 ± 0.7
II	707.3 ± 24.8	12.5 ± 0.5
Below AT	709.5 ± 21.5	13.7 ± 1.0
Above AT	642.4 ± 37.9[a]	9.4 ± 1.1[a]

Mean ± SEM
[a] Significant at $p < 0.05$

Blood lactate concentration during the 60 min Above AT and Below AT warm-up exercise is presented in Fig. 1. During Above AT exercise, there was a significant rise in blood lactate concentration from min 5 to min 20 ($p < 0.05$). Thereafter, there was no further significant increase. Blood lactate was significantly higher at all sampling times for Above AT exercise when compared with Below AT exercise ($p < 0.05$). There was no singificant increase in blood lactate above resting levels for Below AT exercise. Rectal temperature (Fig. 2) increased significantly from pre-exercise to 60 min with increases of 0.6° C

($p < 0.05$) and 1.5° C ($p < 0.05$) for Below AT and Above AT exercise, respectively. After 30 min of exercise, Above AT rectal temperature was significantly higher than Below AT.

Total work output on the two 40 s maximal tests and peak blood lactate concentration (Table 2) significantly ($p < 0.05$) decreased by 9.4% and 25.4%, respectively, following Above AT as compared with Below AT warm-up exercise.

Discussion

Subjects were unaware of the purpose of the present study and they did not demonstrate the slightest hesitancy toward mounting the cycle ergometer without warm-up (conditions I and II) and pedalling "all out" for 40 s. This probably would not be the case for a more familiar task such as running the 400 m dash in which prior stretching and warm-up procedures are considered standard. Performance of such a task without warm-up could result in a less than maximal effort for fear of injury to unstretched muscles. This may help explain conflicting conclusions of previous warm-up studies. In the present study, the Below AT warm-up resulted in a significant increase in core temperature, no increase in steady state blood lactate concentration, and no increase in work output in the following maximal test when compared with experimental conditions I and II. The fact that the cycle ergometer was used as the warm-up mode as well as the maximal performance mode suggests that temperature in the muscles responsible for the maximal performance was elevated. These results suggest that task specific warm-up exercise does not contribute to an increased maximal performance of the type employed in the present study.

Work output and peak blood lactate concentration following the Above AT warm-up was significantly decreased. Each of the five subjects completed the 60 min exercise period without obvious signs of fatigue. The mean blood lactate concentration of 4.2 mM at the end of the 60 min is considerably lower than concentrations prior to maximal exercise in previous studies in which maximal performance was not impaired (Weltman et al. 1977, 1979). This suggests that elevated blood and/or muscle lactate concentration prior to maximal performance probably did not significantly contribute to decreased work output. It is also unlikely that peak blood lactate concentration decreased because of an inability of the muscles to drive lactate levels higher. Previous data (Stamford et al. 1978) revealed similar peak blood lactate concentrations (approximately 16 mM) over a series of three maximal performances separated by 10 min each even though performance time and work output significantly decreased. Glycogen depletion may be a contributing factor.

Gollnick et al. (1973) reported that 60 min of cycling at 67% of $\dot{V}O_2$ max resulted in more than a 50% depletion of muscle glycogen in untrained subjects. It is not unreasonable to suggest that muscle glycogen may have been depleted to a similar degree following 60 min of Above AT exercise at 68% of $\dot{V}O_2$ max in the present study. Whether glycogen depletion influenced work output and lactate production is open to question. In general, glycogen availability has been dismissed as a limiting factor in maximal exercise of short duration. Studies by Karlsson (1971a), Klausen et al. (1975), Asmussen et al. (1974), and Maughan and Poole (1981) reported decreased blood and/or muscle lactate concentrations following maximal work preceded by prolonged submaximal exercise. This suggests a relationship between muscle glycogen content and peak lactate concentration. Saltin and Hermansen (1967) did not find a correlation between muscle glycogen content and peak muscle lactate concentration when muscle glycogen was increased above normal levels. Notwithstanding the lack of correlation between these variables, there is the possibility that a threshold glycogen level exists below which peak muscle/blood lactate concentration is reduced. Karlsson (1971b) studied the effects of severe versus moderate glycogen depletion following submaximal exercise of varying durations on peak muscle lactate concentration. No effect was found for moderate depletion, but a significant decrease in muscle lactate was found when muscle glycogen was severely depleted. Similar results were reported by Jacobs (1981) and this supports a threshold relationship rather than a continuum.

This threshold may impact short duration maximal intensity exercise such as the 400 m sprint differently from prolonged exercise such as marathon running. Differences in impact may be explained on the basis of differing fiber types in skeletal muscle. During moderate intensity exercise similar to the Below AT warm-up, the slow twitch (ST) fibers are primarily recruited whereas at higher intensities of exercise such as the Above AT warm-up there is greater dependence on fast twitch (FT) fibers (Gollnick et al. 1974). High intensity prolonged submaximal exercise may result in glycogen depletion of FT fibers while ST fibers sustain adequate glycogen levels. Depletion of glycogen in FT fibers would seem to especially influence short duration maximal exercise of the type employed in this study. Therefore, although glycogen level is thought not to influence performance until it is depleted to near zero levels as would exist in the final stages of a marathon race, the present data suggest that a lesser degree of glycogen depletion may also influence performance. Specifically, the final 400 m sprint of a 10 km race may be slower if glycogen availability is reduced in FT fibers. Scheele et al. (1979) reported that the best runners in a 10 km race demonstrated the highest post race peak blood lactate concentrations. As such, it may be reasonable to promote glycogen supercompensation techniques for middle distance as well as long distance events if there is concern for a strong sprint at the conclusion of the race.

In summary, prolonged warm-up exercise below AT resulting in a significantly increased core temperature and no increase in blood lactate concentration did not contribute to increased work output. This suggests that warm-up exercise does not contribute to improved maximal performance when the psychological aspects of testing are tightly controlled. Maximal performance following prolonged warm-up exercise above AT was impaired. Peak blood lactate concentration was also reduced. This may be a product of limited glycogen availability in FT fibers with respect to the demands of short term maximal exercise.

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