Effect of Warm-Up on Cycle Time Trial Performance

AMANDA HAJOGLOU[1], CARL FOSTER[1], JOS J. DE KONING[2], ALEJANDRO LUCIA[3],
THOMAS W. KERNOZEK[1], and JOHN P. PORCARI[1]

[1]University of Wisconsin-La Crosse, La Crosse, WI; [2]Vrije Universiteit, Amsterdam, THE NETHERLANDS; and [3]European University of Madrid, Madrid, SPAIN

ABSTRACT

HAJOGLOU, A., C. FOSTER, J. J. DE KONING, A. LUCIA, T. W. KERNOZEK, and J. P. PORCARI. Effect of Warm-Up on Cycle Time Trial Performance. *Med. Sci. Sports Exerc.*, Vol. 37, No. 9, pp. 1608–1614, 2005. **Purpose:** This study was designed to determine the effect of warm-up on 3-km cycling time trial (TT) performance, and the influence of accelerated $\dot{V}O_2$ kinetics on such effect. **Methods:** Eight well-trained road cyclists, habituated to 3-km time trials, performed randomly ordered 3-km TT after a) no warm-up (NWU), b) easy warm-up (EWU) (15 min comprised of 5-min segments at 70, 80, and 90% of ventilatory threshold (VT) followed by 2 min of rest), or c) hard warm-up (HWU) (15 min comprised of 5-min segments at 70, 80, and 90% VT, plus 3 min at the respiratory compensation threshold (RCT) followed by 6 min of rest). $\dot{V}O_2$ and power output (SRM), aerobic and anaerobic energy contributions, and $\dot{V}O_2$ kinetics (mean response time to 63% of the $\dot{V}O_2$ observed at 2 km) were determined throughout each TT. **Results:** Three-kilometer TT performance was ($P < 0.05$) improved for both EWU (266.8 ± 12.0 s) (−2.8%) and HWU (267.3 ± 10.4 s) (−2.6%) versus NWU (274.4 ± 12.1 s). The gain in performance was predominantly during the first 1000 m in both EWU (48% of gain) and HWU (53% of gain). This reflected a higher power output during the first 1000 m in both EWU (384 W) and HWU warm-up (386 W) versus NWU (344 W) trials. The mean response time was faster in both EWU (45 ± 10 s) and HWU (41 ± 12 s) versus NWU (52 ± 13 s) trials. There were no differences in anaerobic power output during the trials, but aerobic power output during the first 1000 m was larger during both EWU (203 W) and HWU (208 W) versus NWU (163 W) trials. **Conclusions:** During endurance events of intermediate duration (4–5 min), performance is enhanced by warm-up irrespective of warm-up intensity. The improved performance is related to an acceleration of $\dot{V}O_2$ kinetics. **Key Words:** CYCLING, ENERGY SYSTEMS, SPORTS PERFORMANCE, $\dot{V}O_2$ KINETICS

There is a widespread belief that warm-up contributes to improved athletic performance (3). Reflecting this, athletes practice several types of warm-up, the most common being an active warm-up involving muscular exercise of varying intensity, often similar in character to the competitive performance. Previous studies have demonstrated that a number of physiological changes occur with active warm-up, some of which are potentially capable of improving performance, particularly during high-intensity exercise. These include increases in heart rate (1,26), acceleration of $\dot{V}O_2$ kinetics due to higher O_2 availability to the working muscles at the onset of exercise (4,5,7,17,19,25), or decreases in lactate accumulation (18,23,27). Other studies have found conflicting results, suggesting that an active warm-up does not produce significant physiological changes that might be expected to enhance performance (21,22,26). If the warm-up is too prolonged or vigorous, the athlete may begin competition with either large disturbances of homeostasis (proton accumulation or buffer reserve depletion) or substrate (creatine phosphate or glycogen) depletion, either of which might mimic the situation to be expected midway through the competitive event and hamper performance (3,17).

Given the amount of focus and importance that athletes place on warm-up, there is a surprisingly limited amount of research evaluating whether active warm-up improves performance. A recent review by Bishop (3) summarized the effects of a variety of warm-up strategies on performance in brief (<10 s), intermediate (10–300 s), and long (>300 s) events. Critical to the effectiveness of the warm-up was allowing the athlete to begin the event at an elevated muscle temperature and $\dot{V}O_2$, but relatively unfatigued. Bishop's summary of the literature suggested improvements in performance during intermediate-duration events following a

---

Address for correspondence: Carl Foster, Ph.D., Department of Exercise and Sport Science, 133 Mitchell Hall, University of Wisconsin-La Crosse, La Crosse, WI 54601; E-mail: foster.carl@uwlax.edu.

Submitted for publication November 2004.
Accepted for publication March 2005.

0195-9131/05/3709-1608/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/01.mss.0000177589.02381.0a

relatively low-intensity warm-up, but potential deterioration following a higher intensity (>70% $\dot{V}O_{2max}$) warm-up unless an adequate recovery period is taken between the end of the warm-up and the beginning of the criterion event. More research was recommended due to the scarcity of well-controlled studies in the field. Unfortunately, actual warm-up procedures are usually based on trial-and-error experience of the athlete or coach, rather than on controlled trials.

The purpose of this study was to determine whether warm-up contributes to improved performance in a 3000-m cycle time trial (i.e., high-intensity intermediate-duration event). We hypothesized that warm-up would accelerate $\dot{V}O_2$ kinetics, which would allow either a faster early pace and/or preservation of anaerobic energy expenditure until later in the race, resulting in less slowdown during the terminal portions of the event.

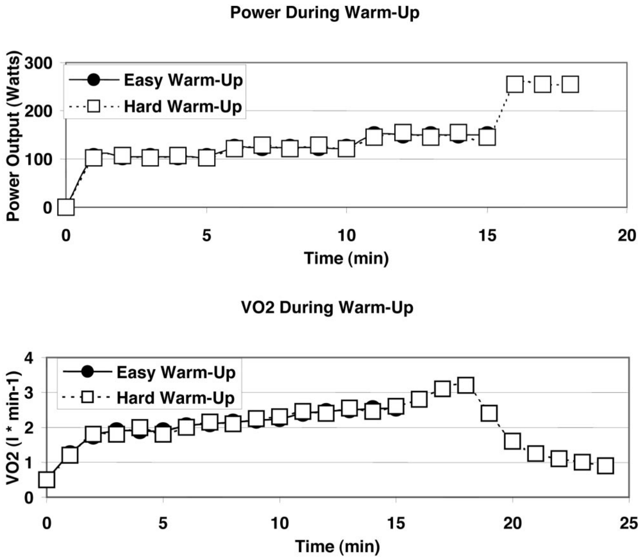

FIGURE 1—Pattern of power output (*top*) and $\dot{V}O_2$ (*bottom*) during and after the warm-up. The $\dot{V}O_2$ at the end of the warm-up matches the $\dot{V}O_2$ at the beginning of the respective time trial.

METHODS

After providing informed consent, eight well-trained cyclists participated in this study. The institutional review board for the protection of human subjects of the University of Wisconsin-La Crosse approved the study protocol. The subjects were local class cyclists and triathletes, training 10–15 h·wk^{-1}. On the average (±SD), the subjects were 31 ± 8 yr of age, their height was 178 ± 5 cm, and their body mass was 73.1 ± 4.2 kg. Their $\dot{V}O_2$ peak during incremental cycle ergometer exercise at a power output of 334 ± 42 W was 4.39 ± 0.76 L·min^{-1}. Ventilatory threshold (VT) was observed at 165 ± 15 W at a $\dot{V}O_2$ of 2.75 ± 0.33 L·min^{-1}. The respiratory compensation threshold (RCT) was observed at 254 ± 25 W at a $\dot{V}O_2$ of 3.42 ± 0.39 L·min^{-1}. All of the subjects were very familiar with cycle time trials by virtue of participating in previous studies (13,14).

Testing protocol. The subjects restricted their training to no more than 30 min at easy/moderate intensity on the day before each testing session. Before the time trails, each subject had performed an incremental test (3 min at 25 W + 25 W·min^{-1} until fatigue) on an electrically braked cycle ergometer (Lode, Groningen, The Netherlands) to determine ventilatory (VT) and respiratory compensation (RCT) thresholds and $\dot{V}O_{2peak}$. Respiratory gas exchange was measured by open circuit spirometry using a mixing chamber–based system (Quinton Q-MC, Seattle, WA). VT and RCT were determined as described by Lucia (25). $\dot{V}O_2$ peak was accepted as the greatest continuous 30-s $\dot{V}O_2$ value observed during the incremental exercise test.

Each subject subsequently performed four 3-km TT on a racing bicycle attached to a wind load simulator equipped with a heavy flywheel (Findly Road Machine, Toronto, CA). We have used this ergometer extensively in our previous studies and have found that it mimics cycling performance very well (10,11,13,14). The cycle was equipped with a chain ring-crank/crank based dynamometer (SRM Koingskamp, Germany) that accurately measures speed, distance completed, cadence, power output (PO; W), and time. The subjects could continuously view both the distance completed and the momentary velocity, just as they would in a normal TT. During the TT, the only instruction given to the subject was to complete the TT is the smallest time possible, as in a competition. Although the subjects had access to information about momentary velocity and power output, there were no protocol-related constraints on how the subject should perform the trial. The first of the four TT was a habituation trial designed to ensure that the subject was fully familiarized with the task. The warm-up for this trial included a 5-min segment at a PO just below that requiring VT. Determination of $\dot{V}O_2$, RER, and PO allowed computation of cycling gross efficiency (15), which was assumed to be constant for all subsequent trials, an assumption justified by previous studies in our laboratory (13,14) and elsewhere (16). The next three TT, with different warm-up strategies, were performed in random order. The warm-up protocols (Fig. 1) consisted of the following: 1) *no warm-up:* subjects sat on the ergometer for 6 min and then began the TT; 2) *easy warm-up:* a 15-min warm-up that included 5-min segments at a PO of 70, 80, and 90% VT, followed by a 2-min rest before the start of the TT; and 3) *hard warm-up:* a 15-min warm-up that included 5-min segments at a PO of 70, 80, and 90% VT, plus 3 min at the intensity of the RCT; followed by a 6-min rest before the start of the TT. The longer recovery duration in the hard warm-up trial was chosen to allow $\dot{V}O_2$ to complete the rapid decrease phase following the conclusion of the warm-up and to be relatively constant between the two warm-up trials. Blood lactate concentration was measured in capillary blood samples obtained from a finger tip before any exercise was performed, at the end of the warm-up, immediately (<30 s) before the TT, and following each TT (at 1, 3, 5, and 10 min postexercise). Lactate concentration was measured in buffered hemolyzed samples using an enzyme electrode system (YSI Sport, Yellow Springs, OH).

Mechanical work was calculated to allow determination of aerobic and anaerobic energetic use every 100 m during the TT. The work (J) attributable to aerobic metabolism was calculated by multiplying metabolic work and efficiency (6,13,14,29). The work attributable to anaerobic sources was calculated by subtracting the work attributable to aerobic metabolism from total work accomplished (6,16,29).

$\dot{V}O_2$ kinetics were found by using a one-component, four-parameter model, conceptually similar to that used by Bell et al. (2). $\dot{V}O_2$ kinetics were calculated using a least squares fit of the $\dot{V}O_2$ responses during the first 2 km of the ride. Because in many cases the subjects accelerated during the last kilometer (with a subsequent increase in $\dot{V}O_2$), we felt that the fairest way to express $\dot{V}O_2$ kinetics was from resting to the 2-km mark. The model was as follows:

$$\dot{V}O_2 = \dot{V}O_{2\mathrm{rest}} + A(1 - e^{-\mathrm{lambda}*(\mathrm{time}-\mathrm{td})})$$

where $\dot{V}O_2$ is oxygen uptake, $\dot{V}O_2$rest is mean $\dot{V}O_2$ during the minute before the start of the TT, A is the calculated highest $\dot{V}O_2$ from the data fit at 2 km, lambda is the time constant and td is the time delay (calculated). Mean response time (MRT) was the most important variable we calculated. The MRT is the time at which the fitted $\dot{V}O_2$ response is 63% of the maximum response (A) at 2 km, plus the time delay (td) of the system. 1/lambda allows the calculation of the variable tau, which is the 63% response time. Therefore, MRT = tau + td.

Statistical analysis. Statistical analysis was performed using repeated measures ANOVA, with warm-up and distance as main effects, to test the hypothesis that warm-up leads to faster completion of TT. Alpha was set at 0.05 to achieve statistical significance. Tukey's test was performed *post hoc* when significant differences were found.

RESULTS

There was a significant difference in the total time required to complete the 3-km TT depending on the warm-up condition (Table 1). Both the hard (267.3 ± 10.4 s) and easy warm-up (266.8 ± 12.0 s) were significantly ($P < 0.05$) faster than the no–warm-up condition (274.4 ± 12.1 s). The time required to complete progressive 500-m segments of the TT also reflected the effect of warm-up (see Fig. 2 for segment times).

The total PO throughout each TT is presented in Figure 3. There was a general pattern for PO to be highest near the beginning of the trial. The average PO during the first 500 m of the hard warm-up trial (431 ± 103 W) was significantly greater than during the easy warm-up trial (421 ± 93 W), and both hard and easy warm-up trials elicited higher mean PO than the no–warm-up trial (378 ± 76 W). Over the next 1000 m the average PO during the easy warm-up TT was significantly greater than during the no–warm-up TT. During the last 1500 m, there were no significant differences in PO among any of the trials. $\dot{V}O_2$ increased rapidly at the beginning of the TT (Fig. 4). There was a significant lag in the rate of increase in $\dot{V}O_2$ during the no–warm-up TT, leading to a significantly longer MRT (52 ± 13 s) compared with the easy (45 ± 10 s) and hard (41 ± 12 s) TT, which were not significantly different from each other. $\dot{V}O_2$ reached substantially constant values through the midportion of each trial, and then increased during the finishing effort in all trials.

TABLE 1. Serial values for cumulative time, power output, and $\dot{V}O_2$ during the 3-km time trials in relation to warm-up strategy.

Distance (m)	Hard Warm-Up	Easy Warm-Up	No Warm-Up
	Time (s)		
500	44.2 ± 4.5	44.8 ± 4.2	45.8 ± 6.0[a]
1000	87.7 ± 7.1	87.9 ± 7.1	91.5 ± 6.3[a]
1500	132.7 ± 8.6	132.4 ± 9.1	138.1 ± 8.1[a]
2000	178.2 ± 9.7	177.8 ± 10.5	184.4 ± 9.8[a]
2500	223.7 ± 10.8	223.3 ± 11.9	230.6 ± 11.8[a]
3000	267.3 ± 10.4	266.8 ± 12.0	274.4 ± 12.1[a]
		Power Output (W)	
500	431 ± 103	421 ± 93	378 ± 76[a]
1000	342 ± 51	347 ± 58	310 ± 37[a]
1500	310 ± 31	315 ± 44	286 ± 31[a]
2000	304 ± 24	304 ± 32	289 ± 40[a]
2500	305 ± 20	305 ± 30	293 ± 37
3000	343 ± 36	354 ± 34	342 ± 49
		$\dot{V}O_2$ ($L \cdot min^{-1}$)	
500	2.50 ± 0.28	2.51 ± 0.35	1.88 ± 0.56[a]
1000	3.78 ± 0.58	3.58 ± 0.50	3.05 ± 0.70[a]
1500	4.21 ± 0.59	4.01 ± 0.57	3.66 ± 0.52[a]
2000	4.27 ± 0.57	4.11 ± 0.47	3.93 ± 0.44[a]
2500	4.24 ± 0.59	4.11 ± 0.52	3.95 ± 0.50
3000	4.63 ± 0.35	4.48 ± 0.43	4.26 ± 0.40

[a] No warm-up vs easy and hard warm-up, $P < 0.05$.

Differences in PO attributable to aerobic and anaerobic sources are presented in Figure 5. The PO attributable to aerobic sources during the hard warm-up TT was significantly greater than the no–warm-up TT for every 500-m segment. The PO attributable to aerobic sources during the easy warm-up trial was greater than in the no–warm-up in all but two of the 500-m segments. There were no significant differences in the PO attributable to anaerobic sources during any of the 500-m segments of the time trial. There were no significant differences in total (3025 ± 167, 3044 ± 230, and 2901 ± 165 J), aerobic (2403 ± 304, 2265 ± 266, and 2108 ± 222 J), and anaerobic (623 ± 191, 779 ± 155, and 794 ± 161 J) work in the hard, easy, and no–warm-up trials, respectively.

Blood lactate concentration at the conclusion of the warm-up in the hard warm-up trial was significantly greater than during either the no–warm-up or easy warm-up trials, although there was no significant difference in blood lactate concentration at the moment that the time trials began (Fig. 6). There was no difference in the peak blood lactate concentration reached after the TT in relation to warm-up, or to the time point following the time trail at which peak blood lactate concentration occurred (e.g., 3 min for all three trials).

DISCUSSION

The present study was designed to answer three questions. The first question was whether there would be an

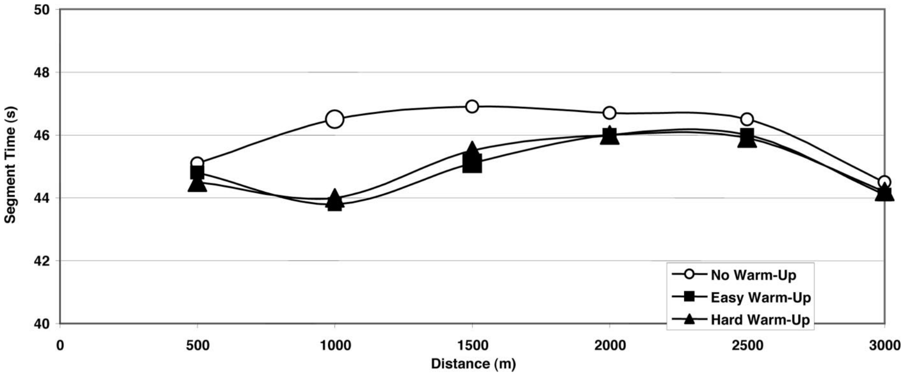

FIGURE 2—Time required to complete successive 500-m segments of the 3-km TT in relation to the warm-up condition. Asterisks represent statistically significant differences between the no–warm-up trial and the easy and hard warm-up trials. There were no significant differences between the easy and hard warm-up

improvement in 3-km TT with warm-up; the second was whether a harder warm-up was more effective than an easier warm-up. The third question was whether there was an acceleration of $\dot{V}O_2$ kinetics with warm-up that might spare anaerobic energy reserves. The results demonstrated a positive effect of warm-up on performance, although our findings failed to demonstrate an advantage of a more intense warm-up. The performance advantage attributable to warm-up appeared to be largely a function of the acceleration of $\dot{V}O_2$ kinetics, as there was no difference in either the magnitude or pattern of anaerobic energy use in relation to warm-up condition. However, as the TT were entirely self-paced, differing patterns of power output during the early moments of the ride could independently have influenced $\dot{V}O_2$ kinetics. Thus, with the present experimental design it is impossible to determine whether the slower $\dot{V}O_2$ kinetics during the no–warm-up trial are independently related to the warm-up, or simply an artifact of the lower power output during the first 1500 m of the no–warm-up trial.

The performance enhancement related to warm-up observed in this study is generally comparable with the earlier study of Grodjinovsky (20), which is the best of the performance-oriented warm-up studies, and with the general conclusions presented in the summary article of Bishop (3). Although we did not study the effects of warm-up in performance during long (>300 s) events, the advantage evident in the present study was during the early moments of the TT, suggesting that after 3–4 min of heavy exercise, the response pattern is very similar whether a warm-up is performed or not. Just as Grodjinovsky found no difference in $\dot{V}O_{2peak}$ without performing a warm-up, we observed no significant difference in the highest $\dot{V}O_2$ reached by our subjects during the last 500 m of any of the trials.

One of the primary proposed mechanisms by which a warm-up is thought to contribute to improved performance is by acceleration of aerobic metabolism, either through an increase in resting $\dot{V}O_2$ (4) or by acceleration of $\dot{V}O_2$ kinetics (7). The results of the present study are compatible with both, the correlation between the higher $\dot{V}O_2$ in the two warm-up trials combined and the time savings ($r = 0.68$) was significant. Not only was the resting $\dot{V}O_2$ higher after both warm-up protocols compared with the no–warm-up trial, but the mean response time (an index of $\dot{V}O_2$ kinetics) was shorter after both warm-up protocols compared with the no–warm-up trial. A recent report by DeLory et al. (7) suggested that prior heavy exercise (e.g., warm-up) was not only associated with accelerated $\dot{V}O_2$ kinetics, but also with a reduction in muscle O_2 desaturation during rest to exercise transitions. The reduction in desaturation was thought to reflect an augmentation of muscle blood flow and oxygen delivery after warm-up. Previous studies from our laboratory (12) have suggested that the time course of decreasing the systemic vascular resistance at the onset of either incremental or steady-state exercise is comparable with the duration of both warm-up protocols. Reductions in systemic vascular resistance would be predicted to augment blood flow delivery to the active musculature. Other studies from our laboratory have demonstrated abnormalities of ventricular function during the beginning moments of heavy exercise performed without warm-up (8), which were largely normalized by warm-up (9). Such abnormalities of ventricular function, although most probably attributable to a mismatching of changes in left ventricular preload and afterload, could still compromise forward cardiac output and interfere with appropriate delivery of blood flow to the exercising musculature.

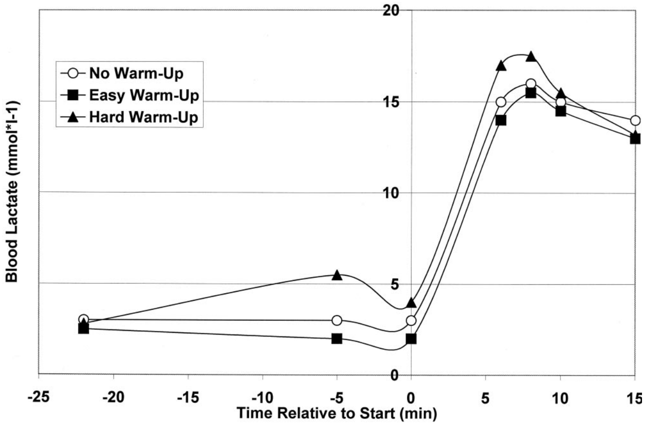

FIGURE 3—Power output during each 100-m segment of the 3-km TT in relation to the warm-up condition. To save space individual significant differences are not indicated, but are summarized in Table 1 for 500-m segments. All significant differences occurred during the first 1500 m of the TT.

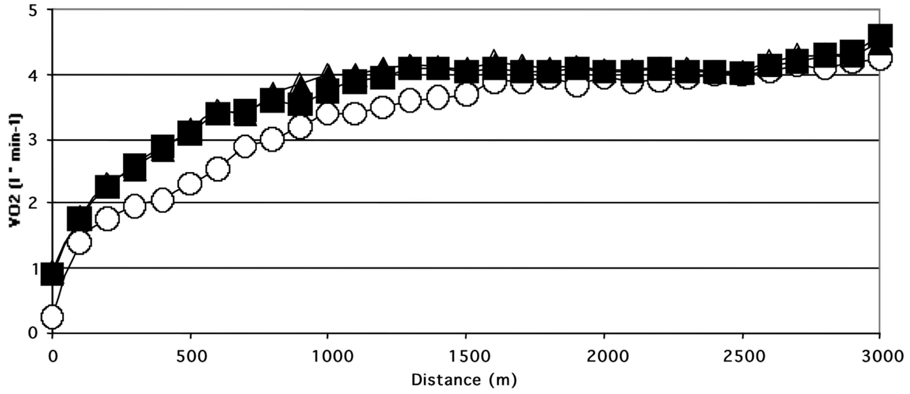

FIGURE 4—$\dot{V}O_2$ during each 100-m segment of the 3-km TT in relation to the warm-up condition. To save space individual differences are not indicated, but are summarized in Table 1 for 500-m segments. All significant differences occurred during the first 1500 m of the TT.

The failure to observe a greater augmentation in performance following the more extensive warm-up is consistent with either a saturation of the warm-up effect, as suggested in the report of Bishop (3), or residual fatigue from the more extensive warm-up. The similar values of blood lactate concentration just before exercise, however, suggests that fatigue that might be associated with elevations of blood lactate concentrations is not a likely cause. Given the comparative brevity of both warm-up protocols, it seems unlikely that depletion of muscle glycogen is an important issue. Together with the report of Bishop (3), the present results are consistent with the concept that a very extensive warm-up is unnecessary for this type of intermediate-duration effort.

Considering the degree to which changes in skeletal muscle mechanics are thought to change with increases in temperature, and the possibility that the abnormalities of left ventricular function may be ischemic in origin (even in healthy individuals with a low likelihood of atherosclerotic disease (8)), the present results may be consistent with one of the main tenets of the recently proposed teleoanticipation hypothesis (21). This hypothesis postulates that much of the pattern of energy expenditure during spontaneous exercise can be understood in terms of a subconscious drive to protect the body from unreasonable demands. Although more research is obviously necessary, the spontaneous downregulation of exercise intensity during the first moments of exercise in the no–warm-up condition would not only provide time for changes in muscle temperature to occur, but would also allow time for the dilation of the coronary vasculature. Subsequent studies of very heavy exercise performed similar warm-up protocols, but with a constant early power output would be instructive relative to whether the differences in $\dot{V}O_2$ kinetics are directly related to the

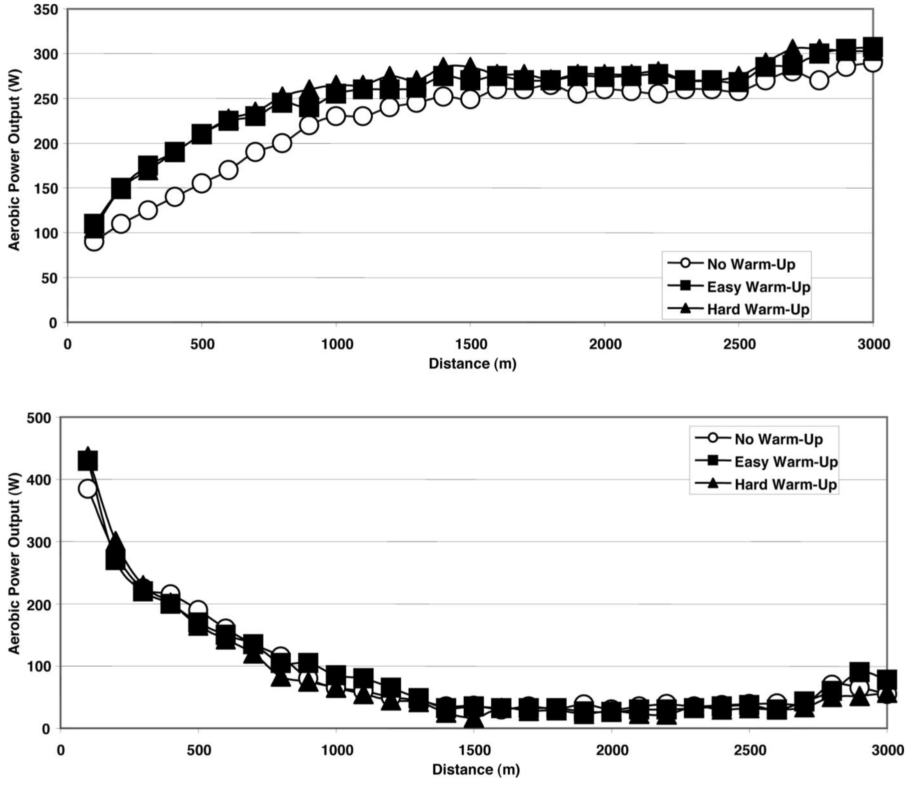

FIGURE 5—Calculated aerobic and anaerobic contributions to power output during each 100-m segment of the 3-km TT in relation to the warm-up condition. There were significant differences in the aerobic contribution to power output only during the first 1500 m of the TT. There were no significant differences in the anaerobic contribution to power output.

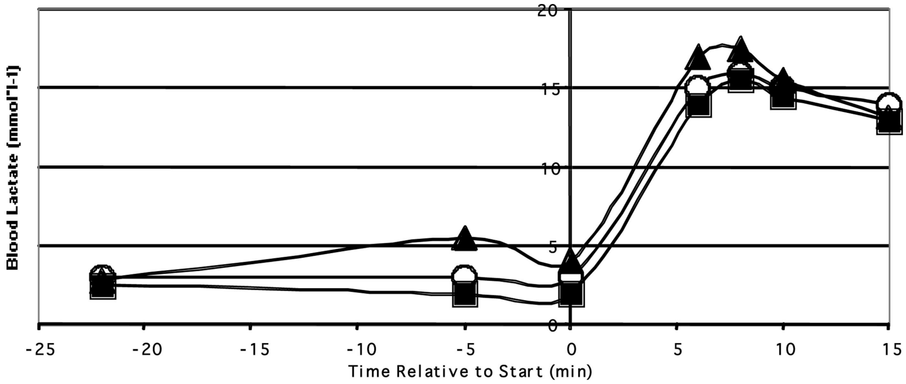

FIGURE 6—Pattern of blood lactate accumulation during the 3-km TT in relation to the warm-up condition. Although there was a significantly greater blood lactate concentration at the end of the hard warm-up trial, there was no difference in blood lactate concentration immediately before the beginning of the trial, nor were there differences during the postexercise period.

warm-up or secondary to the lower power output in the no–warm-up trial.

One of the limitations of this study is the necessity of assuming that efficiency measured during submaximal exercise is representative of efficiency during very high–intensity exercise. This is an untested assumption, constrained by lack of an accepted method of measuring efficiency during high-intensity exercise. If for no other reason, the profound increase in ventilation, which the substantial increase in the $\dot{V}O_2$ attributable to breathing, would be expected to reduce the efficiency of exercise. However, until an acceptable method can be developed to measure changes in efficiency, we feel that there is sufficient precedent to use the efficiency, which was calculated as in previous studies (13,14,16).

The present study demonstrates that there is a significant improvement in cycle TT performance attributable to warm-up, the magnitude of performance enhancement being about 2–3%. Such performance enhancement seems to be associated with an augmentation of aerobic metabolism attributable to warm-up rather than to a sparing of anaerobic energetic sources (24,28).

REFERENCES

1. Andzel, W. D. The effects of moderate prior exercise and varied rest intervals upon cardiorespiratory endurance performance. *J. Sports Med.Phys. Fit.* 18:245–252, 1978.
2. Bell, C., D. H. Peterson, J. M. Kowalchuk, J. Padilla, and D. A. Cunningham. A comparison of modeling techniques used to characterize oxygen uptake kinetics during the on-transient of exercise. *Expl. Physiol.* 86.5:667–676, 2001.
3. Bishop, D. Warm Up II. Performance changes following active warm-up and how to structure the warm-up. *Sports Med.* 33:483–498, 2003.
4. Burnley, M., A. M. Jones, H. Carter, and J. H. Doust. Effects of prior heavy exercise on phase II pulmonary oxygen uptake kinetics during heavy exercise. *J. Appl. Physiol.* 89:1387–1396, 2000.
5. Chwalbinska-Moneta, J., and O. Hanninen. Effect of active warming-up on thermoregulatory, circulatory, and metabolic responses to incremental exercise in endurance-trained athletes. *Int. J. Sports Med.* 10:25–29, 1989.
6. de Koning, J. J., C. Foster, J. Lampen, F. Hettinga, and M. F. Bobbert. Experimental evaluation of the power balance model of speed skating. *J. Appl. Physiol.* 99:227–233, 2005.
7. DeLorey, D. S., J. M. Kowalchuk, and D. H. Paterson. Effects of prior heavy-intensity exercise on pulmonary O_2 uptake and muscle deoxygenation kinetics in young and older adult humans. *J. Appl. Physiol.* 97:998–1005, 2004.
8. Foster, C., J. D. Anholm, C. Hellman, J. Carpenter, M. L. Pollock, and D. H. Schmidt. Left ventricular function during sudden strenuous exercise. *Circulation.* 63:592–596, 1981.
9. Foster, C., D. S. Dymond, J. G. Carpenter, and D. H. Schmidt. Effect of warm-up on the left ventricular response to sudden strenuous exercise. *J. Appl. Physiol.* 53:380–383, 1982.
10. Foster, C., A. C. Snyder, N. N. Thompson, M. A. Green, M. Foley, and M. Schrager. Effect of pacing strategy on cycle time trial performance. *Med. Sci. Sports Exerc.* 25:383–388, 1993.
11. Foster, C., M. A. Green, A. C. Snyder, and N. N. Thompson. Physiological responses during simulated competition. *Med. Sci. Sports Exerc.* 25:877–882, 1993.
12. Foster, C., R. A. Gal, P. Murphy, S. C. Port, and D. H. Schmidt. Left ventricular function during exercise testing and training. *Med. Sci. Sports Exerc.* 29:297–305, 1997.
13. Foster, C., J. J. deKoning, F. Hettina, et al. Pattern of energy expenditure during simulated competition. *Med. Sci. Sports Exerc.* 35:826–831, 2003.
14. Foster, C., J. J. deKoning, F. Hettinga, et al. Effect of competitive distance on energy expenditure during simulated competition. *Int. J. Sports Med.* 25:198–204, 2004.
15. Garby, L, and A. Astrup. The relationship between the respiratory quotient and the energy equivalent of oxygen during simultaneous glucose and lipid oxidation and lipogenesis. *Acta Physiol. Scand.* 129:443–444, 1987.
16. Gastin, P. B., D. L. Costill, D. L. Larson, K. Krzeminski, and G. K. McConnell. Accumulated oxygen deficit during supramaximal all out and constant intensity exercise. *Med. Sci. Sports Exerc.* 27:255–263, 1995.
17. Genovely, H., and B. A. Stamford. Effects of prolonged warm-up exercise above and below anaerobic threshold on maximal performance. *Eur. J. Appl. Physiol.* 48:323–303, 1992.
18. Gerbino, A., S. A. Ward, and B. Whipp. Effects of prior exercise on pulmonary gas-exchange kinetics. *J. Appl. Physiol.* 80:99–107, 1996.
19. Gray, S., and M. Nimmo. Effects of active, passive or no warm-up on metabolism and performance during high intensity. *J. Sports Sci.*19:693–700, 2001.
20. Grodjinovsky, A., and J. Magel. Effect of warm up on running performance. *Res Quart.* 41:116–119, 1970.
21. Hampson, D. B., A. St Clair Gibson, M. I. Lambert, and T. D. Noakes. The influence of sensory clues on the perception of

exertion during exercise and central regulation of exercise performance. *Sports Med.* 31:935–952, 2001.

22. Howard, G. E., C. S. Blyth, and W. E. Thornton. Effects of warm-up on the heart rate during exercise. *Res. Quart.* 37:360–367, 1966.
23. Kaufmann, D. A., and W. B. Ware. Effect of warm-up and recovery techniques on repeated running endurance. *Res. Quart.* 48:328–332, 1977.
24. Knowlton, R. G., D. S. Miles, and M. N. Sawka. Metabolic responses of untrained individuals to warm-up. *Eur. J. Appl. Physiol.* 40:1–5, 1978.
25. Lucia, A., J. Hoyos, A. Santalla, C. Earnest, and J. L. Chicharro. Tour de France vs Vuelta a Espana: Which is harder? *Med. Sci. Sports Exerc.* 35:872–878, 2003.
26. MacDonald, M., P. Pedersen, and R. L. Hughson. Acceleration of $\dot{V}O_2$ kinetics in heavy submaximal exercise by hyperoxia and prior high intensity exercise. *J. Appl. Physiol.* 83:1318–1325, 1997.
27. Martin, B. J., S. Robinson, D. L. Wiegman, and L. H. Aulick. Effect of warm-up on metabolic responses to strenuous exercise. *Med. Sci Sports.* 7:146–149, 1977.
28. Robergs, R. A., D. D. Pascoe, D. L. Costill, and W. J. Fink. Effects of warm-up on muscle glycogenolysis during intense exercise. *Med. Sci. Sports Exerc.* 25:37–43, 1990.
29. Seresse, O., J. A. Simoneau, C. Bouchard, and M. Boulay. Aerobic and anaerobic energy contribution during maximal work in 90s determined with various ergocycle workloads. *Int. J. Sports Med.* 12:543–547, 1991.