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Effects of different interval-training programs on cycling time-trial performance

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Outline

Graphics

ABSTRACT

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Purpose: We have investigated the effect of varying the intensity of interval training on 40-km time-trial performance in 20 male endurance cyclists (peak oxygen uptake 4.8 ± 0.6 L·min^{-1}, mean ± SD).

Methods: Cyclists performed a 25-kJ sprint test, an incremental test to determine peak aerobic power (PP) and a simulated 40-km time-trial on a Kingcycle ergometer. They were then randomly assigned to one of five types of interval-training session: 12 × 30 s at 175% PP, 12 × 60 s at 100% PP, 12 × 2 min at 90% PP, 8 × 4 min at 85% PP, or 4 × 8 min at 80% PP. Cyclists completed 6 sessions over 3 wk, in addition to their usual aerobic base training. All laboratory tests were then repeated.

Results: Performances in the time trial were highly reliable when controlled for training effects (coefficient of variation = 1.1%). The percent improvement in the time trial was modeled as a polynomial function of the rank order of the intensity of the training intervals, a procedure validated by simulation. The cubic trend was strong and statistically significant (overall correlation = 0.70, P = 0.005) and predicted greatest enhancement for the intervals performed at 85% PP (2.8%, 95%CI = 4.3-1.3%) and at 175% PP (2.4%, 95%CI = 4.0-0.7%). Intervals performed at 100% PP and 80% PP did not produce statistically significant enhancements of performance. Quadratic and linear trends were weak or insubstantial.

Conclusions: Interval training with work bouts close to race-pace enhance 1-h endurance performance; work bouts at much higher intensity also appear to improve performance, possibly by a different mechanism.

The scientific literature on the unique effects of specific training interventions on the performances of well-trained individuals is sparse. To date, sports scientists have found it difficult to persuade highly trained competitive athletes to experiment with their normal training programs. Owing to the scarcity of data in this area, we have recently undertaken a series of investigations into the effects of interval training on the performance of competitive endurance cyclists (8,12,16,17). These studies have all employed the same training intervention, namely, replacing a portion (~15%) of an athletes aerobic base training with sustained (5 min) high-intensity (90% of maximal oxygen uptake [[latin capital V with dot above]O_{2max}]) work bouts (for review see refs. 6,8). In the present study, we have expanded on our previous work by investigating the effect of work bouts of different durations and intensities in an attempt to identify the best training stimulus for enhancing endurance exercise performance.

The conventional approach to investigating the response to different doses of a treatment is to perform a repeated-measures study in which each subject receives all the different doses. The data are then best analyzed by modeling trends in the response to the different doses with polynomial (linear, quadratic, etc.) or other appropriate mathematical functions of the dose (10). The resulting curve of best fit allows prediction of a maximum and minimum response, the dose that produces these responses, the range of doses that give substantial or significant responses, and so on. Unfortunately, this approach is impractical for studies of athletic training, because the long-lasting effects of a given dose of training prevent subjects from receiving more than one dose of the treatment. The only solution is to conduct a series of studies, each with a different training dose and a different set of subjects. The training dose that produces the biggest response, for example, could then be identified by performing a series of pairwise comparisons between the doses. However, a novel and potentially more powerful approach would be to adapt the strategy recommended by Holbert et al. (10) by fitting polynomial or other curves to the responses for each dose. We have used this approach in the present study.

METHODS

Twenty provincial-level male endurance-trained cyclists were recruited for this investigation, which was approved by the Research and Ethics Committee of the University of Cape Town Medical School. All of the cyclists had previously been laboratory tested and were fully acquainted with the nature of the investigation before they signed consent forms. The cyclists had been training for and competing in endurance cycle races on a regular basis for a minimum of 3 yr, and none had undertaken any interval training in the 3-4 months preceding this study.

Figure 1 shows the schedule of baseline testing, the training program, and postintervention testing. Each set of laboratory tests was conducted on two occasions at the same time of day separated by 3 d. Two days after completing the final training session, each cyclist repeated the same set of tests.

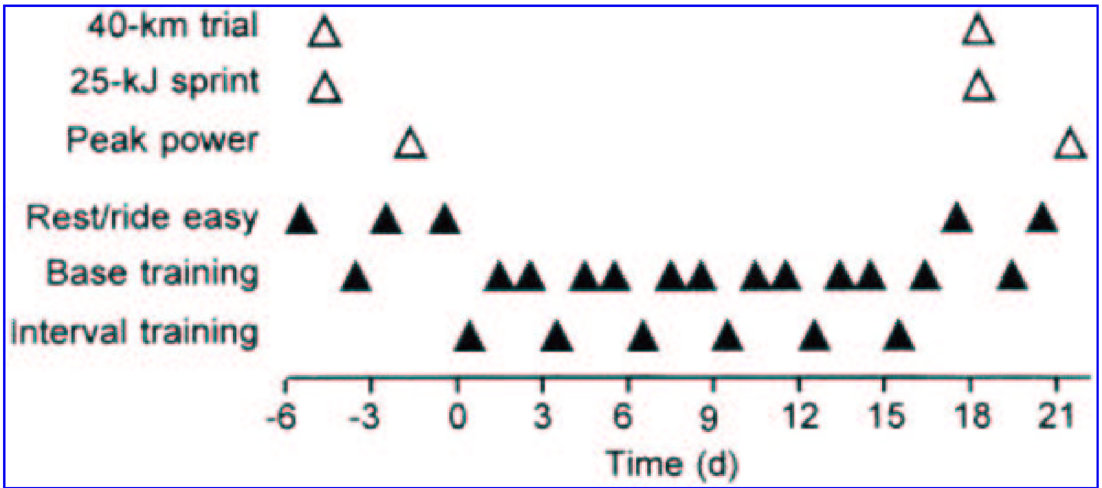

Figure 1-The timetable of laboratory testing and training sessions.

Testing regimen. Cyclists refrained from heavy training and consumed their normal diet for the 24 h preceding each visit to the laboratory. On arrival in the laboratory, cyclists were weighed to the nearest 0.1 kg in their cycling shorts on a Seca precision balance (Model 770, Bonn, Germany). Their body mass was used to determine the starting work rate in the subsequently described exercise performance tests. Skin-fold thickness at the biceps, triceps, subscapular, and supra-iliac sites were used to estimate percent body fat (4).

Each cyclist then performed a 25-kJ sprint test on an electronically braked cycle ergometer (Lode, Gronigen, The Netherlands), modified with clip-in pedals, a racing saddle, and a low-profile handlebar. Before each test, the saddle height and handlebar position of the ergometer were adjusted to the subject’s requirements, and he warmed-up at a self-selected exercise intensity and duration. The amount of work performed in the first warm-up was recorded and repeated before subsequent exercise tests. After the warm-up, the subject completed a 25-kJ sprint "as fast as possible." A short warm-down was followed by 30 min of complete rest, during which the cyclist sat quietly. Each cyclist then performed a simulated 40-km time trial on his own racing bike, which was mounted on an air-braked ergometer (Kingcycle Ltd., High Wycombe, Buckinghamshire, UK). The bike was attached to the ergometer by the front fork and supported by an adjustable pillar under the bottom bracket. The bottom bracket support was used to adjust the rolling resistance of the rear tire on an air-braked cycle flywheel. The calibration procedures for the Kingcycle ergometer have been described in detail previously (15).

After the Kingcycle was calibrated, the cyclist commenced a 5-min warm-up at a self-selected exercise intensity, which was replicated for all subsequent time trials. Cyclists rode the time trial "as fast as possible," and the only feedback they received was the elapsed distance. The coefficient of variation (CV) of the time taken by a competitive cyclist to complete the time trial is ~1% (15).

Three days later, each cyclist returned to the laboratory and performed an incremental exercise test to exhaustion on the Lode cycle ergometer, as previously described (9). Briefly, this test commenced at a starting load of 3.3 $W \cdot kg^{-1}$. This load was maintained for 150 s, then increased first by 50 W, then 25 W every 150 s until the cyclist was exhausted. Exhaustion was defined as a drop in the pedaling rate of > 10 $rev \cdot min^{-1}$ and/or a rise in respiratory exchange ratio (RER) of >1.1. Peak sustained power output (PP) was defined as the last completed work rate in W plus the fraction of time spent in the final noncompleted work rate multiplied by 25 W.

During the incremental test to exhaustion, the cyclist breathed into a naso-oral mask connected to an automated gas analyzer (Model Alpha, Oxycon Ltd., Mijnhardt, The Netherlands). Before each test, the analyzer was calibrated with a Hans Rudolph 3-L syringe, room air, and a 5% CO_2:95% N_2 gas mixture. Analyzer outputs were processed by a computer, which calculated ventilation ([latin capital V with dot above]$_E$), oxygen consumption ([latin capital V with dot above]O_2), and CO_2 expiration ([latin capital V with dot above]CO_2) for each breath, using conventional equations. Peak [latin capital V with dot above]O_2 was taken as the average of the highest [latin capital V with dot above]O_2 measured over the final 30 s of the test.

The PP value was used to determine the work rates for two submaximal steady-state rides, consisting of 10 min at 50, 60, 70, and 80% of PP. During the final 5 min of each work rate, expired air was sampled and rates of carbohydrate oxidation were estimated from the equations of Frayn (5), assuming a nonprotein RER. In the last 60 s of each work rate, blood samples (3 mL) were drawn from a 20-gauge cannula, inserted in a forearm vein and attached to a 3-way stop-cock. Each blood sample was placed into a tube containing potassium oxalate and sodium fluoride and stored on ice until the end of the test. The tubes were then centrifuged at 2500 ×*g* for 10 min at 4°C and the supernatants were stored at -20°C for subsequent measurements of plasma lactate concentrations by a spectrophotometric (Model 35, Beckman Instruments Inc., Fullerton, CA) enzymatic assay (Lactate PAP, BioMerieux, Lyon, France).

During the maximal incremental exercise test and the steady-state rides, heart rates (HR) were measured and stored by a Sports tester monitor (Polar Electro OY, Kempele, Finland). The monitor consisted of an electrode belt worn around the chest, a transmitter, and a wrist-mounted receiver. The receiver recorded momentary HR at 5-s intervals during for the incremental test and 15-s intervals during the steady-state rides.

Training interventions. After all the preliminary testing, cyclists were randomly assigned to one of five interval-training protocols. Each cyclist performed a total of six interval-training sessions over a 3-wk period (Fig. 1). All laboratory-training sessions were supervised by the same investigator and performed on the same cycle ergometer under standard environmental conditions (ambient temperature 20-22°C, relative humidity 55-60%). Specific details of the work:rest ratios and the intensity of each of the different training interventions are given in Table 1. Each laboratory training session lasted for ~60 min. The training protocols were devised in consultation with coaches, cyclists, and sports scientists to represent training sessions that well-trained riders would be willing to undertake during preparation for a competition. The amount of work performed in each interval training session could not be standardized because work is not a linear function of exercise intensity: cyclists can ride at 75% of PP for 2 h (7), but they can ride at 150% of PP for only ~1 min (11).

Training Group	No. of Work Bouts	Duration of Work Bouts (min)	Intensity (% PP)	Rest Interval (min)
1	12	0.5	175	4.5
2	12	1.0	100	4.0
3	12	2.0	90	3.0
4	8	4.0	85	1.5
5	4	8.0	80	1.0

PP, peak sustained power output attained during the maximal test.
During the rest interval subjects cycled at a work rate of 100 W.

TABLE 1. A summary of the five interval-training protocols.

From the onset of the investigation each cyclist recorded his training distance, duration and perceived training effort in a logbook. These records were used subsequently to calculate the weekly endurance-training distances that the cyclists were able to undertake during the investigation. As the aim of the current investigation was to produce a training environment for the cyclists (and their coaches) that was "as normal as possible," the only restriction on the training outside the controlled laboratory sessions was that, for the duration of the study, cyclists were not to undertake any interval training.

Statistics. Before this study, we performed simulations to determine the sample size that would give acceptable confidence intervals for terms in a polynomial ($y = a + bx + cx^2 + dx^3 + \ldots$), and acceptable 95% confidence intervals (CI) for the predicted enhancements for each training protocol. In these simulations, the training protocol was a variable that ranged from -1 for the shortest (30 s) to +1 for the longest (8 min) intervals. These values for the training-protocol variable simplified interpretation of the coefficients in the polynomials. Data were generated that had no real polynomial effects, because data without effects need the largest sample sizes to define the magnitude of the effects with acceptable precision. With 20 subjects, a coefficient of variation for an individual's performance of 1%, and a quadratic model, the 95%CI for the linear (b) and quadratic (c) terms was ± 0.9% and ± 1.5% respectively; with a cubic model, the 95%CI were ± 2.7%, ±1.5%, and ± 3.0% for the linear, quadratic and cubic (d) terms, respectively. These numbers represent confidence limits for the difference in performance contributed by each term in the polynomial between athletes in the middle group (x = 0) and the extreme groups (x = 1). These CI therefore seem reasonably acceptable in the quadratic model (which was the model we expected to use) but are rather wide for the linear and cubic terms in the cubic model (which we did not expect to be applicable). The 95%CI for predicted enhancement were ± 1.0% and ± 1.4% for the middle and extreme groups, respectively, with the quadratic model, and only marginally wider (±1.0% and ± 1.5%) with the cubic model. These seem acceptable for both models.

All performance data were converted to a percentage change via the transformation log [(post measurement)/(pre measurement)] (11). These data were then modeled as polynomial functions of the rank-ordered intensity of the training protocols using Proc Reg in version 6.12 of the Statistical Analysis System (SAS Institute, Cary NC).

Goodness-of-fit of the polynomials was expressed as an overall correlation coefficient (R), calculated by taking the square root of the fraction of variance explained by the model, after adjusting for degrees of freedom. Relationships between measures of performance in the first time trial, and between changes in performance between the two time trials, were expressed as Pearson correlation coefficients.

Reliability of performance in the exercise tests was calculated as intraclass correlation coefficients and CV. These were derived by repeated-measures of the log-transformed variables, with training protocol as a between-subject nominal (classification) effect. Reliability calculated in this way represents the reproducibility of performance under conditions of the experiment, after controlling for any changes in mean performance in each experimental group. The analyses were performed with Proc Mixed in SAS.

Means and standard deviations are used throughout as measures of centrality and spread of data. CI shown for outcome measures have a 95% chance of enclosing the population mean. Outcomes with $P < 0.05$ were regarded as statistically significant.

RESULTS

Descriptive statistics of the subjects are shown in Table 2. One cyclist failed to complete the prescribed training program and was eliminated from the study. Table 3 shows the baseline performance for the simulated 40-km time trial, the maximal incremental test, and the 25-kJ sprint, whereas Figure 2 shows the percentage change in performance in these tests for the individual cyclists after training.

Training Group	N	Age (yr)	Mass (kg)	$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	Body Fat (%)
1	4	26 ± 4	78 ± 15	4.7 ± 0.4	15 ± 4
2	3	24 ± 5	70 ± 20	4.4 ± 1.2	15 ± 3
3	4	28 ± 1	73 ± 4	5.1 ± 0.5	11 ± 3
4	4	27 ± 7	80 ± 8	4.9 ± 0.3	12 ± 3
5	4	26 ± 6	78 ± 8	4.8 ± 0.3	16 ± 4

$\dot{V}O_{2peak}$, peak oxygen uptake measured during the maximal incremental test.
Data are mean ± SD.

TABLE 2. Characteristics of subjects in each training group.

Training Group	40-km Time Trial (min)	Peak Power Output		25-kJ Sprint Test (s)
		W	$W \cdot kg^{-1}$	
1	57.3 (4)	372 (29)	4.8 (0.7)	41 (5)
2	60.3 (5)	350 (95)	5.0 (0.2)	50 (20)
3	53.6 (1)	403 (20)	5.5 (0.2)	41 (5)
4	55.9 (3)	390 (25)	4.9 (0.2)	43 (5)
5	53.7 (3)	385 (18)	4.9 (0.4)	45 (6)

Data are mean ± SD.

TABLE 3. Baseline laboratory performance measures.

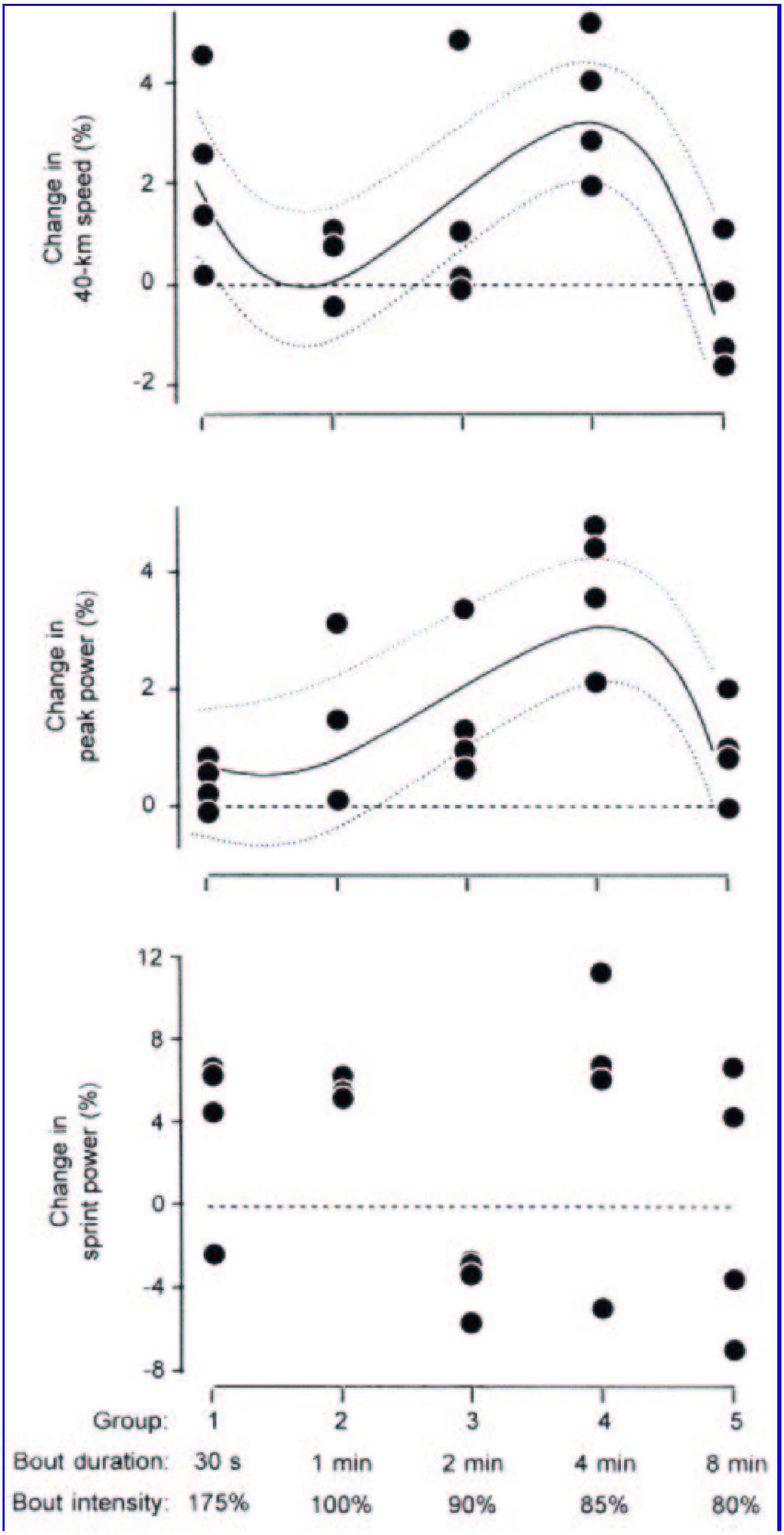
Change in
40-km speed (%)
4
2
0
-2
Change in
peak power (%)
4
2
0
Change in
sprint power (%)
12
8
4
0
-4
-8
Group: 1 2 3 4 5
Bout duration: 30 s 1 min 2 min 4 min 8 min
Bout intensity: 175% 100% 90% 85% 80%

Figure 2-Percentage change in 40-km time-trial speed (*upper panel*), peak sustained power output (*middle panel*), and 25-kJ sprint power (*lower panel*) after the five interval-training programs.

Data for the 40-km time trial showed a strong, statistically significant cubic trend (R = 0.70, $P = 0.005$). Linear and quadratic trends did not the data well (R = 0.14, $P = 0.30$ and R = 0.08, $P = 0.4$, respectively). The reliability of performance in this time trial was high (CV = 1.1%). The maximal incremental test also showed a strong cubic trend (R = 0.62, $P = 0.02$), but a quadratic trend was also statistically significant (R = 0.51, $P = 0.03$). A linear trend was not apparent (R = 0.30, $P = 0.1$). Reliability of this test was also high (CV = 1.0%). The reliability of the sprint test was poor (CV = 3.4%), and the linear, quadratic, and cubic trends were inconsequential (R < 0.1 and P = 0.4-0.8).

Improvements in 40-km time-trial performance were not associated with any significant differences in fuel utilization. Both before and after interval training, the rates of carbohydrate oxidation during the steady-state rides increased from 2.4 ± 0.2 $g \cdot min^{-1}$ at 50% of PP to 3.4 ± 0.3, 4.1 ± 0.3, and 5.4 ± 0.4 $g \cdot min^{-1}$ at 60, 70, and 80% of PP, respectively. There were also no differences in the corresponding rises in plasma lactate concentration at increasing work rates. Concentration of plasma lactate increased from 2.4 ± 0.3 $mmol \cdot L^{-1}$ at 50% of PP to 3.3 ± 0.6, 3.5 ± 0.8, and 7.3 ± 1.0 $mmol \cdot L^{-1}$ at 60, 70, and 80% of PP, respectively. HR were also not significantly different. Before and after interval training, HR increased progressively from 137 ± 6 $beats \cdot min^{-1}$ at a work rate of 50% of PP to 171 ± 9 at 80% of PP.

Peak power was highly correlated with 40 km time-trial performance time (r = -0.82, 95%CI = -0.93 to -0.58; $P = 0.0002$) both before and after training, but the percentage change in PP after training did not correlate with the corresponding changes in performance (r = -0.09, 95%CI = -0.52 to 0.38; $P = 0.9$). However, as would be expected, the changes in the percentage of PP that cyclists could sustain after the various interval training sessions was highly correlated with the changes in time-trial performance (r = -0.92, $P = 0.0001$).

DISCUSSION

In the present study, we used a novel approach to the problem of studying the effect of different types of training on human physical performance. The most important finding was a substantial curvilinear relationship between training intensity and the subsequent change in performance of a simulated 40-km time trial. The relationship predicted a maximum enhancement in performance after work bouts with a duration of 3-6 min and an intensity of ~85% of PP. The enhancement observed for these work bouts of approximately ~2.5% agrees well with previous findings (12,16). The prediction of a maximum enhancement of performance after work bouts undertaken at ~85% of PP is also in accord with the principle of specificity, inasmuch as the 40-km time-trial is performed at an average intensity of approximately 80% of PP (or ~90% of [latin capital V with dot above]O_{2max}).

The primary component of the curvilinear relationship is a polynomial cubic, which predicts little or no enhancement of performance for 1- and 8-min work bouts and a substantial enhancement of performance for 30-s work bouts. We expected a simpler trend: for example, better performance with longer intervals (a linear trend), or a single maximum or a simple curve (a quadratic trend). Such trends did not fit the data well. Our failure to detect simpler trends was not a methodological problem, because these well-trained cyclists had high reliability in performance, similar to that of cyclists employed in previous studies from our laboratory (CV = 0.9-1.2%) (12,15,16). The simulations based on such reliability showed that we would have detected a small linear or quadratic trend, if one were present.

We cannot discount the possibility that the apparent strength of the cubic trend is a chance finding and that the real underlying relationship has a weaker or nonexistent cubic component and stronger quadratic or linear components. We would need to test even more subjects to be more certain about the nature of the trend. At this stage, however, the cubic trend passes the more stringent test of significance ($P < 0.01$), so we must assume it is real. Why then did 30-s work bouts produce an enhancement of performance whereas 1-min work bouts did not? According to the principle of specificity, the 30-s work bouts, which would have been achieved by a substantial contribution from oxygen-independent glycolysis, would not enhance performance of a 40-km time trial, which depends almost entirely on power provided by the aerobic system (7). However, this view of specificity could be overly simplistic. It is possible, for example, that the high-intensity work bouts effect adaptations in the working muscle that lead to enhanced fatigue resistance, perhaps by altering skeletal muscle buffering capacity (14). The nature of the fatigue mechanism is a mystery; indeed, it is not even clear whether muscle is the site of fatigue in high-intensity exercise lasting 1 h. In view of our uncertainty about such a basic phenomenon, we feel it is reasonable that 30-s work bouts could benefit endurance performance.

To the best of our knowledge, there are no other published studies of the effect of such short intense work bouts on endurance performance in already well-trained athletes. The only other study to investigate the effects of increasing training intensity in well-trained subjects was that of Acevedo and Goldfarb (1). They found that seven trained runners who increased a portion of their 100 km·wk $^{-1}$ training for 8 wk with high-intensity (90-95% of maximal HR) running 3 d·wk $^{-1}$ significantly improved both their laboratory run time to exhaustion (19:25 vs 23:18 min:s) and also their 10-km race time (34:24 vs 35:27 min:s). Coetzer et al. (3) have also reported that runners with superior race performances train at a higher average intensity than their slower counterparts: their slower runners spent 13% of their total weekly training volume performing high-intensity (>80% of [latin capital V with dot above]O_{2max}) running, whereas the faster runners spent significantly more time (36%) at this higher intensity. They hypothesized that more intense training might allow the athlete to sustain a higher fraction of [latin capital V with dot above]O_{2max} or power output for a longer period without the accumulation of lactate in the working muscles (3). Such an hypothesis is consistent with the observation of a reduced plasma lactate concentration at the same absolute work rate (80% of PP) after intense interval training (16). Additionally, Weston et al. (17) have previously reported that six sessions of high-intensity training in well-trained cyclists resulted in a significant improvement in muscle buffering capacity, which was closely correlated with 40-km time-trial performance (r = -0.82). Of interest was the finding that the enhancement of muscle buffering capacity in the study of Weston et al. (17) after 5-min work bouts at 80% of PP was greater than that reported by Nevill et al. (14) after 8 wk of sprint training. Previous investigations that have employed short duration (<30 s) sprint-training programs have reported that such interventions increase 5-s maximal power and even short-term (30-s) performance (13,14). However, none of these studies has determined whether sprint training has any effect on endurance performance. Paradoxically, we have previously reported that sustained (5-min) interval training improved the performance of a maximal sprint test lasting ~60 s (12). It should be noted that the contribution from aerobic power systems to a maximal 30-s work bout is ~40% while such a contribution rises to 50% during a 1-min all-out effort (for review see ref. 7).

The second finding of the present study was a strong curvilinear trend in the effect of interval training on peak power determined during the maximal incremental test. Once again, a cubic trend gave the best fit and predicted a maximum improvement in performance (~3%) for 4-min work bouts. Unlike the trend in 40-km time-trial performance, there was no apparent tendency for enhancement of performance for the shortest work bouts, and a quadratic trend-which would predict a peak in performance enhancement closer to the center of the range of training doses-may be more appropriate for these data. Previous studies using 5-min work bouts at 80-85% of peak power have resulted in increases in PP of ~5% (12,16). In agreement with these studies, there was no significant correlation between the change in peak power and 40-km time. In these earlier studies, the lack of correlation could be due to the fact that all subjects underwent the same training and improved by a similar amount within each test. Any variability in performance was therefore probably less than the error of measurement, so a large correlation would not be possible. In addition, the sample sizes in those studies were relatively small for defining a correlation coefficient with any reasonable precision, so a moderate correlation could easily have been missed. In the present investigation, there was a range in performance enhancements in both tests. Moreover, the larger sample size in the present study allowed greater precision of the estimate of the correlation. Therefore, at best, there can be only a moderate correlation between changes in performance in the two tests. The lack of a strong correlation suggests that interval training produces different responses between individuals in 40-km time-trial performance and peak power. Others have also noted significant differences in the response to a training stimulus (2). A practical ramification of the training principle of individuality is that the same training program will not equally benefit all those athletes who undertake it (6).

The third and final laboratory measure of performance in the current study, the sprint test, proved to be relatively unreliable. The lack of any curvilinear trend in the response to the different training protocols is therefore not surprising because we would be unlikely to detect changes of a few percent that may have occurred with the different interval-training protocols.

In conclusion, the results of the present investigation show that work bouts of 4-min duration at race pace resulted in the greatest enhancement of performance in a simulated 40-km time trial and also in a maximal incremental test to determine peak power. Trends in enhancement indicated that very short high-intensity work bouts can also enhance endurance performance. The apparent nadir in enhancement between 30-s and 4-min intervals suggests that there is more than one mechanism by which interval training enhances performance. However, further research is needed to confirm this concept and elucidate the possible mechanisms responsible for such improvement. Finally, the effects of different types of interval training on sprint performance need investigating with a more reliable test of sprinting.

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