

High-Resistance Interval Training Improves 40-km Time-Trial Performance in Competitive Cyclists

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Interval training at race-specific high cadences improves endurance cycling performance, but there is evidence that adding resistance to reduce the cadence might be more effective. **AIM.** To determine the effect of high-resistance interval training on endurance performance of male cyclists during the competition phase of a season. **METHODS.** In a randomized controlled trial, 10 cyclists in a control group maintained usual training and competing while 12 cyclists in an experimental group replaced part of their usual training with high resistance interval training twice weekly for 8 wk. Mean power in a 40-km simulated time trial, maximal oxygen consumption ($\text{VO}_{2\text{max}}$), incremental peak power, body composition, and leg strength were measured before and after training. **RESULTS.** Relative to control training, there were clear beneficial effects of resistance training on 40-km mean power (7.6%, 90% confidence limits $\pm 5.0\%$). There were also clear beneficial effects on incremental peak power (3.5%, $\pm 4.2\%$), $\text{VO}_{2\text{max}}$ in $\text{ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ (6.6%, $\pm 7.0\%$), and sum of 8 skinfolds (-12%, $\pm 11\%$). Effects on body mass (-1.6%, $\pm 1.9\%$) and thigh muscle area (0.6%, $\pm 2.7\%$) were possibly trivial. Effects on $\text{VO}_{2\text{max}}$ in $\text{L}\cdot\text{min}^{-1}$ and three measures of isokinetic leg strength were unclear, owing to large errors of measurement. **CONCLUSIONS.** High-resistance interval training produces a major enhancement in endurance power of athletes in the competitive season. The benefits of this form of training should transfer to competitive performance.

KEYWORDS: endurance, strength, $\text{VO}_{2\text{max}}$.

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Update 6Feb06: Correction to peak power in Table 2.

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INTRODUCTION

In a review published at this site last year, Paton and Hopkins (2004) summarized the evidence for beneficial effects of various kinds of high-intensity resistance and interval training on the endurance performance of competitive athletes. Although the gains in endurance power output on average were up to 8%, "all but one study was performed in non-competitive phases of the athletes' programs, when there was otherwise little or no high-

intensity training". They suggested that the gains would probably be less if the high-intensity training were performed in the competitive phase, when athletes normally include higher intensity training in their programs. Indeed, in the only previous training study performed during the competitive phase of a season (Toussaint and Vervoorn, 1990), sport-specific resistance training enhanced competitive time-trial performance of swimmers by an

amount equivalent to a useful but smaller ~2% in power output. In a follow-up study, Paton and Hopkins (2005) observed improvements of 6-9% in various measures of endurance power. Evidently, some forms of resistance training can be very effective, even during a competitive phase.

I was also interested in the benefits of resistance training for endurance performance, and coincidentally performed a study on cyclists during the same competitive season that Paton and Hopkins performed their training study. The outcome is the basis of this paper.

METHODS

Subjects

Twenty-four well-trained male cyclists were recruited through Auckland cycling clubs. All subjects provided informed written consent in accordance with the University of Auckland human subjects ethics committee. All subjects in the study were in the competition phase of their training and were free of injury and illness. A description of the subject groups is shown in Table 1.

Subjects were randomly assigned in to either an experimental high-resistance interval-training or a control normal-training group. Two subjects in the control group withdrew before the completion of the study. Subjects in the experimental group performed eight weeks of supervised high resistance interval training twice per week, in addition to their normal low intensity endurance training. The control group continued with their normal training programs which was a combination of high intensity racing, and low intensity endurance training. All subjects were given detailed training logs to complete four weeks prior to, and during the eight week intervention period. All subjects repeated the testing procedures 4-10 d following the completion of the intervention.

Experimental Measures

Prior to testing, subjects were instructed to refrain from intensive training, caffeine, and alcohol for 24 hours, and to remain on their normal diet. This investigation was a pre-post design, thus the following procedures were conducted within one week pre- and one week post-intervention. All testing procedures allowed a minimum of 48 h recovery between tests. On the first visit to the laboratory, subjects were weighed and sum of eight skinfolds

were measured using skinfold calipers (Holtain, UK). Maximal aerobic capacity ($\text{VO}_{2\text{max}}$) was then measured using an incremental (ramp) protocol with the subject's own racing bicycles mounted on the Kingcycle ergometer (KingCycle, High Wycombe, UK), which was calibrated prior to each test. An initial workload of 100 W was increased 33 W each minute until volitional fatigue. VO_2 was measured from analysis of expired gases (AMETEK OCM-2, Thermox Instruments, Pittsburgh Pa). VO_2 was averaged over 20-s intervals. A computer interfaced with the Kingcycle ergometer measured power throughout the test and peak power was defined as the highest mean power recorded over any 60-second period of the incremental test.

Table 1. Subject characteristics, including baseline performance and anthropometric measures for the control and experimental groups.

	Experimental (n=12)	Control (n = 10)
Age (y)	30 ± 8	32 ± 3
Height (m)	1.8 ± 0.0	1.8 ± 0.1
Body mass (kg)	78 ± 4	79 ± 14
Cycling experience (y)	10.6 ± 6.3	11.2 ± 5.4
Training per week (h)	11.8 ± 4.3	11.0 ± 4.7
Sum of 8 skinfolds (mm)	87 ± 36	87 ± 36
Mid-thigh muscle area (cm ²)	213 ± 19	209 ± 37
$\text{VO}_{2\text{max}}$ (L.min ⁻¹)	4.8 ± 0.4	4.8 ± 0.5
$\text{VO}_{2\text{max}}$ (ml.min ⁻¹ .kg ⁻¹)	61.4 ± 6.0	62.2 ± 8.5
Incremental peak power (W)	469 ± 33	472 ± 72
40-km time (min)	54.0 ± 2.2	54.1 ± 3.2
40-km mean power (W)	317 ± 32	317 ± 52
Peak torque at 180°.s ⁻¹	266 ± 25	239 ± 49
Peak torque at 270°.s ⁻¹	233 ± 26	213 ± 44
Peak torque at 360°.s ⁻¹	205 ± 26	185 ± 32
Data are mean ± standard deviation. $\text{VO}_{2\text{max}}$: maximum oxygen consumption.		

Gluteal and quadricep concentric muscle strength was measured 30 min after the $\text{VO}_{2\text{max}}$ test using a Biodex isokinetic dynamometer. The subject's hip and knee angles were positioned to simulate top dead centre or the start of the power phase of the pedaling cycle as described by Faria and Cavanaugh (1978). The movement involved hip and knee extension to bottom dead centre or just prior to full knee extension. Maximal repetitions at

isokinetic leg speeds of 180, 270 and 360°.s⁻¹ (3.1, 4.7 and 6.3 radians.s⁻¹) were performed five times and peak torque was recorded as the highest of the five values. These speeds equate to 30, 45, 60 revs.min⁻¹ on the bicycle, which represent the range of cadences used in the high-resistance interval-training program.

On a second visit to the laboratory, subjects performed a 40-km cycling time trial on the Kingcycle ergometer. To ensure that subjects gave their maximum effort they were informed that they would receive incremental financial rewards if they completed the time trial at or above 70% of their individual peak power measured on the first visit and post intervention incentives based on improvement. Subjects were permitted to consume fluids ad libitum during the time trial.

Training Intervention

Cyclists in the high resistance interval training group performed prolonged rides in the laboratory twice per week, during which low cadence (40–80 revs.min⁻¹) intervals were performed as suggested by Polishuk (1994). All interval training sessions were supervised by the primary investigator. Sessions consisted of 5–6 intervals of 3 to 22 minutes, and the total interval duration per session increased steadily from 25 min in Week 1 through 55 min in Week 8. Rest periods in between work intervals ranged from 1 to 5 minutes. Cadence was set with a metronome. Subjects pedalled to the set cadence using the highest gear on their bicycles and graded resistance on the simulators to maintain the highest power output for the cadence. Average and maximum heart rate were recorded using heart rate monitors (Polar, Kempele, Finland). Power output in Watts was manually recorded from the Cateye simulators every minute during the work intervals. Due to small but consistent differences in ergometers (Cateye and Kingcycle), power output was then re-calculated to give an approximation of Kingcycle power output in Watts from the regression equations developed during pilot work.

Statistics

Each dependent variable was analyzed with a published spreadsheet that used log transformation to estimate the effect of training as the difference in the mean percent change between the experimental and control groups (Hopkins, 2003). Each spreadsheet provided precision of

the estimate as 90% confidence limits and as chances the true effect was practically beneficial and harmful. For calculation of the chances of benefit and harm, the following values of smallest worthwhile effects were entered into the spreadsheet for each variable: 1.5% and 0.65% for 40-km mean power and time respectively (Paton and Hopkins, 2006); 1.5% for peak power, VO₂max, and power-to-weight ratio (on the assumption that changes in these variables translate directly into changes in mean power in a time trial); and a standardized mean difference of 0.20 for all other measures (Hopkins, 2003). Practical inferences were drawn using the approach described elsewhere in this journal (Batterham and Hopkins, 2005). Briefly, if chance of benefit and harm were both >5%, the true effect was assessed as unclear (could be beneficial or harmful). Otherwise, quantitative chances of benefit or harm were assessed qualitatively as follows: <1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99, very likely; >99%, almost certain. Each spreadsheet also calculated a standard deviation representing individual responses to the treatment (typical variation about the mean effect from subject to subject) and another standard deviation representing the typical error of measurement in the control group between pre and post tests.

RESULTS

There was little difference in mean characteristics and baseline performance in the two groups (Table 1). The main effect of the intervention period was a substantial enhancement of performance in the 40-km time trial, due mainly to an enhancement in the experimental group and a relatively small impairment in the control group (Table 2). The nett effect on VO₂max was similar in magnitude when expressed relative to body mass but a little smaller and unclear when expressed in absolute units. The experimental group also experienced a substantial reduction in skinfold thickness relative to the control group, but changes in body mass and mid-thigh muscle area were more likely to be trivial. The isokinetic testing produced unclear outcomes.

Standard errors of measurement for the control group between pre and post tests were: 40-km time-trial time, 1.7%; 40-km time-trial mean power, 4.3%; incremental peak power,

4.8%; VO₂max (ml.min⁻¹.kg⁻¹), 7.7%; VO₂max (L.min⁻¹), 7.5%; body mass, 1.8%; sum of 8 skinfolds, 11%; mid-thigh muscle area, 2.3%; and peak torques, 8-11%. The 90% confidence limits for the true values of the error of measurement were $\times/\div 1.5$ for all measures.

Standard deviations representing individual responses had too much uncertainty for any firm conclusions; for example, the value for 40-

km time-trial mean power was 4.4%, but the 90% confidence limits were -5.2% to 8.4%. About half the measures had negative standard deviations for individual responses (owing to greater variation in the change scores in the control group), but the confidence limits all allowed for the possibility of substantial real individual responses.

Table 2. Effect of 8 weeks of high resistance interval training on cycling performance, physiological and anthropometric parameters.

	Change in measure (%)			Practical inference ^a
	Experimental mean \pm SD	Control mean \pm SD	Difference; \pm 90%CL	
Performance measures				
40-km time-trial mean power	6.4 \pm 7.7	-1.1 \pm 6.2	7.6; \pm 5.0	Very likely beneficial
40-km time-trial time	-2.3 \pm 2.9	0.6 \pm 2.5	-2.9; \pm 2.0	Very likely beneficial
Incremental peak power ^b	6.1 \pm 3.3	4.1 \pm 5.1	2.0; \pm 3.5	Possibly beneficial
Physiological and anthropometric measures				
VO ₂ max (L.min ⁻¹)	3.8 \pm 6.1	-0.6 \pm 10.8	4.4; \pm 6.7	Unclear
VO ₂ max (ml.min ⁻¹ .kg ⁻¹)	4.6 \pm 6.8	-1.9 \pm 11.1	6.6; \pm 7.0	Probably beneficial
Body mass	-0.8 \pm 2.6	0.8 \pm 2.5	-1.6; \pm 1.9	Possibly trivial
Sum of 8 skinfolds	-8 \pm 14	5 \pm 16	-12; \pm 11	Probably beneficial
Mid-thigh muscle area	2.4 \pm 4.2	1.8 \pm 3.3	0.6; \pm 2.7	Probably trivial
Peak torque at 180° .s ⁻¹	-2 \pm 15	2 \pm 13	-4; \pm 10	Unclear
Peak torque at 270° .s ⁻¹	1 \pm 12	-1 \pm 16	1 \pm 11	Unclear
Peak torque at 360° .s ⁻¹	1 \pm 15	1 \pm 13	0; \pm 10	Unclear
\pm 90%CL: add and subtract this number to the mean effect to obtain the 90% confidence limits for the true difference.				
^a Based on the following smallest worthwhile changes in performance: 1.5% for 40-km mean power, peak power at VO ₂ max, VO ₂ max, and power-to-weight ratio; 0.65% for 40-km time; standardized mean difference of 0.20 for all other measures.				
^b Data shown after deletion of one control subject who showed a decline in performance of 10% in the post test.				

DISCUSSION

The main finding of this investigation was that eight weeks of low-cadence high-resistance interval training improved mean power by ~8% in a 40-km time trial in well-trained male cyclists. Furthermore, these improvements occurred during the competition phase of the racing season, when the cyclists were already training and competing at high intensity. The improvements, and those in incremental peak power and VO₂max, are similar to those in most previous studies of high-intensity interval and resistance training, when the uncertainty in all the estimates is taken into account.

The main difference between the present study and most other previous studies is that the improvements occurred during the competition phase of a racing season, when the athletes were already training and competing at high intensity. Inasmuch as the smallest worthwhile increase in performance for an elite cycling time-trialist is ~1.5% (Paton and Hopkins, 2006), the gains I have observed represent major enhancements. Only two other published studies of effects of high-intensity training on endurance athletes have been performed during a competition phase. The enhancements in my

study were greater than the ~2% observed in a study of swimmers (Toussaint and Vervoorn, 1990), possibly because the low-cadence training I achieved with the cyclists was more effective than the protocol devised for the swimmers. The gain I observed in peak incremental power was possibly less than the 6% Paton and Hopkins (2005) observed with cyclists, but their gains in shorter endurance tests (8-9% in 1-km and 4-km time trials) were similar to what I observed in the 40-km time trial. Their resistance-training sets were similar to ours, but they included sets of ballistic jumps. The contribution of the jumps to performance enhancement is unclear.

Some of the measures of performance in the present study produced unclear outcomes. The problem appears to have been relatively large errors of measurement for those measures. The errors for 40-km mean power, VO₂max, and peak power were twice as large as reported in some reliability studies (Hopkins et al., 2001). The errors in the present study probably reflect real individual variation in performance of the cyclists in the control group over the time frame of the study. There was probably also a substantial contribution of technical (equipment) error to the unacceptably large error of measurement for VO₂max. I agree with Hopkins et al. (2001)

that measures derived from isokinetic ergometry are too noisy to be useful for tracking changes in performance of athletes.

Although my study was aimed primarily at determining the effect of resistance training on endurance performance, I measured several physiological and anthropometric variables that are potentially related to the mechanism of the effect. It is clear that an increase in VO₂max could be the main reason for the increase in endurance performance, but I can only speculate that an enhancement of economy was also involved, as in other studies of the effects of resistance training on endurance (Paton and Hopkins, 2004). A contribution from the other component of endurance, fractional utilization of VO₂max, is another possibility. An increase in body mass could be harmful for cyclists when the course includes hill climbing. Resistance training can increase body mass by increasing muscle mass, but my training protocol appeared to have little effect on thigh muscle mass, and the only change in body mass was trivial. The loss of skinfold thickness is in principle a benefit, but only if it represents a substantial loss of body mass. Whether the loss of skinfold thickness was a direct effect of resistance training or an indirect effect of a change in diet is unclear.

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