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Large Inter-Individual Differences in Responses to a Block of High Intensity Aerobic Interval Training: A Case Series in National-level Cyclists and Triathletes.

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ABSTRACT

International Journal of Exercise Science 13(2): 480-487, 2020. The aim was to investigate individual responses on VO_{2max} and performance to a block of high intensity aerobic interval training (HIIT) in national-level endurance athletes. METHODS: National-level cyclists and triathletes (five men and two women, 31 ± 3.3 years, VO_{2max} 65.1 ± 3.3 ml ·kg^{-1} ·min^{-1}) conducted 14 HIIT sessions (4x4 min uphill running at 90-95% maximal heart rate) in nine days during preseason. VO_{2max} in running and cycling, lactate threshold (LT) in cycling, oxygen cost of cycling (C_C), and a cycling time-trial (TT) were tested two days pre and seven days post intervention. Feasibility was determined using attendance rates, adherence (defined as completing all sessions), and reported adverse events. RESULTS: The results showed that adherence was 100% with 100% attendance rate. No adverse events were reported. TT (-75.6 ± 50.8 seconds, $p < 0.0001$) but not VO_{2max} cycling (-0.2 ± 4.6 ml·kg^{-1}·min^{-1}, $p = 0.53$) or running (0.2 ± 1.2 ml·kg^{-1}·min^{-1}, $p = 0.85$) was improved on group level. The individual responses varied from -8.2% to +14.5% change in VO_{2max}, and -7.5% to +0.8% in TT. CONCLUSIONS: The large inter-individual differences in responses call for tailor-making HIIT blocks, mapping of biomarkers to avoid overtraining, and studying the effects of such blocks with longer follow-up than seven days.

KEY WORDS: Sports, performance, athlete, $VO_{2\,max}$, time-trial, cycling

INTRODUCTION

Maximal oxygen consumption (VO_{2max}) may be considered the most important single physiological variable for aerobic endurance performance (20), and it is well documented that high intensity aerobic interval training (HIIT) is effective (19) and superior to moderate intensity continuous training (11, 12) in improving and maintaining VO_{2max}. Further increasing training volume at moderate intensities does not appear to sufficiently improve endurance performance such as VO_{2max}, anaerobic threshold, economy of motion or oxidative enzymes in well-trained endurance athletes (6, 7). In contrast, HIIT can elicit significant improvements of VO_{2max} in such athletes (8, 10, 13) as well as in untrained and moderately trained individuals (19). Development of endurance training methods to improve VO_{2max} in already well-trained endurance athletes is therefore crucial.

Previous case studies have shown that high-density blocks of HIIT, i.e. 15 HIIT sessions in 9-11 days, can improve both VO_{2max} and time-trial (TT) performance (4, 18). Despite these promising results, such blocks could be contra-productive as the large training loading increases risk of overtraining and injuries (5). Such blocks may also be potential challenging to complete even for well-trained athletes, and could therefore result in low adherence. Furthermore, it is important to increase knowledge regarding inter-individual differences in responses to such blocks in order to enhance tailor-made exercise regimes for the athletes. The promising results found in case studies must therefore be replicated in case series before a full-scale, randomized controlled trial can be conducted. The aim of this study was to investigate individual responses to a block of HIIT among national-level endurance athletes, i.e. cyclists and triathletes.

METHODS

Participants

Seven national-level cyclists and triathletes (five men and two women, three cyclists and four triathletes of which three of them also competed in cycle races) were consecutively recruited through personal contact. Inclusion criterion was being an athlete ranked at national level in cycling and/or triathlon, and exclusion criteria were injuries, illness, schedule which made it impossible to adhere to the training intervention, and BMI < 17 kg/m^2. Baseline characteristics are shown in Table 1. Because this intervention included four VO_{2max} tests, two ergometer-cycle time-trials and fourteen HIIT sessions in 17 days, it was considered demanding even for well-trained national athletes. According to the local Institutional Review Board, we were therefore ethically obliged to recruit as few participants as possible. However, since the aim was not to explore if HIIT was an effective method to improve VO_{2max}, but to explore individual responses to a block of HIIT, power calculations were of minor importance. The same rationale applies to why a control group is not included.

This study was carried out in accordance with the recommendations of Norwegian Data Protection Services with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The Institutional Review Board of former Telemark University College, now University of South-Eastern Norway, approved the protocol. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (16).

Protocol

The subjects performed 14 HIIT running sessions during a 9-day period during preseason. Each session was carried out on a treadmill with 5-10% incline. Running was preferred due to shown higher cardiovascular stress compared to cycling in cyclists and triathletes (2), and due to practical reasons with seasonal variations in the Nordic countries. The sessions consisted of 10-minute warm-up, intervals of 4x4 minutes at 90-95% of HR_{max} with 3-minutes recovery periods at 70% of HR_{max} in between, and 5-10 minutes of cool-down. Absolute intensity i.e. inclination and/or speed was continuously adjusted to keep relative intensity at the prescribed HR. The protocol of the HIIT block is described more in details in previous studies (11, 18, 19).

Incremental VO_{2max} tests (running and cycling), oxygen cost of cycling (C_C), lactate threshold of cycling (LT), and a test-ergometer 23-km cycle time trial (TT) were performed as described in previous studies (18, 19). Pre-tests were carried out on two consecutive days two days pre intervention, while post-tests were carried out on two consecutive days seven days post intervention. The tests were carried out as follows: Day 1: 4x5 minutes of warm-up and LT testing with incremental loading on cycle ergometer (Lode Excalibur Sport, Lode B.V, Groningen, Germany). Arcary Lactate Pro LT-1710-analyzer (Arcary Inc., Kyoto, Japan) was used to obtain blood lactate levels. After 5-minute break, the first VO_{2max} test was performed on cycle ergometer using Vmax Spectra (Sensor Medics, Yourba Linda, USA) to measure VO_{2max}. After the first VO_{2max} test, the participant had 30-minute active recovery before the VO_{2max} test on treadmill (Woodway PPS55, Waukesha, WI, USA) was performed. HR was measured using Polar RS800CX (Polar, Tempele, Finland) and Garmin 910XT (Garmin, Kansas, USA). Day 2 of the testing included the cycle TT. The participants conducted no vigorous intensity training and only small amounts of light-to-moderate intensity training between the end of the intervention and up to post-tests. A schematic illustration of the testing and training sessions is shown in Figure 1.

	V_r				x	x			x	x		x	x								V_r	
	V_c	TT			x	x	x	x	x	x		x	x								V_c	TT
D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	Pretest				Training intervention									Light training							Posttest	

Figure 1. Schematic illustration of the testing and training sessions. D: day. V_r: VO_{2max} running. V_c: VO_{2max} cycling. TT: time-trial cycling. X: 4x4 HIIT training session.

Feasibility was operationalized through attendance rates, adherence (defined as completing all 14 sessions), and registered adverse events. To evaluate subjective training load, the participants reported perceived muscle soreness on a Likert scale from 1 (no muscle soreness) – 10 (extreme muscle soreness), and physical tiredness from 1 (not tired at all) – 10 (extremely tired).

Statistical Analysis

Individual responses were presented as individual changes in percent, i.e. descriptive statistics. For a better over-view of baseline numbers and group responses, group statistics were presented as mean ± standard deviation pre and post intervention, as well as delta values and coefficient of variance in percent. VO_{2max} data are presented in $L \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot min^{-1}$ and allometric scaled as $ml \cdot kg^{-0.67} \cdot min^{-1}$. The allometric scale values are chosen based on recommendations from Åstrand & Rodahl (1), and on previous studies for cycling (20). Pearson's correlation was used for analysis of possible associations between variables, and paired sample t test was used for the pretest-posttest comparison. For the group statistics, the level of significance was set to $p < 0.05$.

RESULTS

The adherence was 100% with 100% attendance rate. No adverse events were reported. TT performance but not VO_{2max} was improved from pre-test to post-test (Table 1). Individual baseline values varied from 1619 – 3748 seconds on TT, and from 198.8 – 292.8 $mL \cdot kg^{-0.67} \cdot min^{-1}$ on cycling VO_{2max} (Table 2).

Table 1. Group results of the HIIT block.

	Pretest (*n* = 7)	Posttest (*n* = 7)	Δ	*p*-value	CV (%)
Age (yrs)	31.9 ± 9.3	31.9 ± 9.3	-	-	-
Height (cm)	179.9 ± 12.4	179.9 ± 12.4	-	-	-
BW (kg)	75.8 ± 16.2	74.9 ± 15.3	-0.9 ± 1.2	0.184	1.5
TT					
Time (s)	2249.4 ± 734.3	2173.9 ± 699.3	-75.6 ± 50.8	0.000***	2.3
Power (W)	270.3 ± 67.7	279.9 ± 69.3	9.6 ± 8.5	0.023*	2.1
$\%VO_{2max}$	83.7 ± 5.7	85.1 ± 5.9	1.5 ± 6.4	0.560	5.3
RER	0.89 ± 0.03	0.90 ± 0.02	0.01 ± 0.0	0.569	2.3
HR ($beats \cdot min^{-1}$)	170 ± 7	170 ± 9	0 ± 4	0.934	2.0
$[La^-]_b$	7.6 ± 2.3	8.6 ± 3.2	1.0 ± 1.7	0.183	14.9
VO_{2max} Cycling					
$mL \cdot kg^{-1} \cdot min^{-1}$	62.6 ± 6.4	62.4 ± 5.6	-0.2 ± 4.6	0.533	5.2
$mL \cdot kg^{-0.67} \cdot min^{-1}$	259.8 ± 33.5	263.5 ± 35.4	3.8 ± 19.1	0.680	5.2
$L \cdot min^{-1}$	4.74 ± 1.06	4.79 ± 1.14	0.05 ± 0.35	0.732	5.2
RER_{peak}	1.07 ± 0.03	1.09 ± 0.04	0.02 ± 0.04	0.197	2.2
HR ($beats \cdot min^{-1}$)	184 ± 9	186 ± 9	2 ± 6	0.467	2.0
$[La^-]_b$	11.2 ± 2.3	11.3 ± 2.8	0.1 ± 0.3	0.599	2.1
VO_{2max} Running					
$mL \cdot kg^{-1} \cdot min^{-1}$	65.1 ± 3.3	65.3 ± 3.2	0.2 ± 1.2	0.830	1.3
$mL \cdot kg^{-0.67} \cdot min^{-1}$	270.6 ± 27.6	270.3 ± 28.2	-0.3 ± 4.6	0.880	1.2
$L \cdot min^{-1}$	4.95 ± 1.10	4.91 ± 1.09	-0.04 ± 0.11	0.730	1.6
RER_{peak}	1.03 ± 0.04	1.04 ± 0.04	0.01 ± 0.03	0.245	2.2
HR ($beats \cdot min^{-1}$)	188 ± 10	189 ± 9	1 ± 7	0.928	2.6
$[La^-]_b$	9.8 ± 1.9	9.4 ± 1.5	-0.4 ± 0.7	0.277	5.2
C_C					
$mL \cdot kg^{-1} \cdot w^{-1}$	0.201 ± 0.05	0.200 ± 0.48	-0.001 ± 0.004	0.564	1.4
$mL \cdot kg^{-0.67} \cdot w^{-1}$	1.039 ± 0.173	1.028 ± 0.144	-0.011 ± 0.025	0.532	1.7
LT					
$\%VO_{2max}$	78.1 ± 0.05	77.9 ± 0.04	-0.2 ± 4.1	0.943	3.6
W	258.3 ± 61.0	263.6 ± 63.0	5.3 ± 20.0	0.724	5.4
MAP (W)	326.5 ± 76.5	333.9 ± 81.0	7.4 ± 21.6	0.403	4.6
Perf Eq (W)	257.7 ± 76.9	286.8 ± 80.6	11.1 ± 12.7	0.059	3.2

Values are mean ± standard deviation, difference ± standard deviation from pre- to post intervention (**Δ**), p values, and coefficient of variance (CV) in change from pre- to post. Yrs: years. Cm: centimeters. BW: body weight. TT: cycling time trial. S: seconds. W: watts. VO2: oxygen consumption. RER: respiratory exchange ratio. HR: heart rate. Min: minutes. $[La^-]_b$: blood lactate concentration. $ml \cdot kg^{-1} \cdot min^{-1}$: milliliters per kilo bodyweight per minute. ml·kg-

$^{0.67}\cdot min^{-1}$: milliliters per kilo bodyweight raised to the power of 0.67 per minute. $L\cdot min^{-1}$: liters per minute. C_C: oxygen cost of cycling. LT: lactate threshold. MAP: maximal aerobic power. Perf Eq: performance equation (MAP · %VO2max in TT). *$p < 0.05$ different from pre. ***$p < 0.001$ different from pre.

Table 2. Individual baseline values.

Subject	TT (sec)	VO_{2max} B ($L\cdot min^{-1}$)	VO_{2max} B ($ml\cdot kg^{-1}\cdot min^{-1}$)	VO_{2max} B ($ml\cdot kg^{-0.67}\cdot min^{-1}$)	MAP (W)	CC ($ml\cdot kg^{-1}\cdot w^{-1}$)
1 (M)	1643	5.5	67.1	288.1	386.3	0.174
2 (M)	1857	5.2	66.5	279.4	367.8	0.181
3 (M)	1619	5.7	67.6	292.8	414.8	0.163
4 (F)	3748	2.6	56.5	198.8	183.6	0.307
5 (M)	2086	4.9	59.2	253.9	332.7	0.178
6 (F)	2397	4.4	68.6	270.2	310.0	0.221
7 (M)	2396	4.9	52.6	235.4	290.5	0.181

TT: time in the cycling time trial. VO_{2max}: maximal oxygen consumption bike (B). C_C: oxygen cost of cycling. MAP: maximal aerobic power.

The individual responses to the HIIT block presented as range in percent changes were VO_{2max} (-8.2 , 14.5), TT (-7.5 , 0.8), C_C (-2.5 , 1.7), maximal aerobic power (MAP) (-6.0 , 12.9), fractional utilization of VO_{2max} in TT (-8.0 , 14.2), LT in %VO_{2max} (-1.2 , 1.3), work at LT (LT_W) (-5.3 , 11.7) (Table 3). The cyclists and triathletes who improved VO_{2max} in running also improved VO_{2max} in cycling. The correlation between baseline VO_{2max} and Δ VO_{2max} was r = .53 (p = 0.28). Mean score for muscle soreness was 2.2 ±1.2, and mean score for physical tiredness was 4.0±1.7. No correlations were found between soreness, tiredness, baseline VO_{2max} and Δ VO_{2max}.

Table 3. Individual responses to the HIIT block.

Subject	Δ TT %	Δ VO_{2max} %	Δ C_C %	Δ MAP %	Δ fract util %	Δ HR %
1 (M)	-4.2	4.8	-1.2	6.6	-5.2	0.3
2 (M)	-1.0	-3.2	1.7	-4.0	2.7	2.7
3 (M)	-2.3	-1.9	-2.5	0.2	2.4	-1.8
4 (F)	-4.1	0.0	-2.0	1.8	-1.8	1.2
5 (M)	-4.4	14.5	1.7	12.9	-8.0	-1.2
6 (F)	0.8	-8.2	-2.3	-6.0	14.2	-0.5
7 (M)	-7.5	5.2	2.2	4.1	3.1	-1.8

All values are expressed as percent changes. TT: time in the cycling time trial in sec. VO_{2max}: maximal oxygen consumption in $ml\cdot kg^{-0.67}\cdot min^{-1}$. C_C: oxygen cost of cycling. MAP: maximal aerobic power in Watts. Fract util: fractional utilization of VO_{2max} during the cycling time trial. HR: heart rate during the cycling time trial.

DISCUSSION

The main findings were the large inter-individual differences in physiological and performance responses to a block of HIIT among national-level cyclists and triathletes. The 14.5% improvement in VO_{2max} in one of the athletes is in close accordance with the case previously reported in Støren et al. (18). The athletes from Breil et al.(4) were alpine skiers, younger and had lower VO_{2max} at pre-test, yet they showed better improvement compared to our study. One possible explanation is the longer intervention duration (11 vs 9 days) with equal time period from last training day to post-test (7 days), which increase chances of reaching super-compensation (14). We cannot exclude the possibility that the lack of group improvements in

VO_{2max} were due to some participants already being near their upper limits, as VO_{2max} adaptations are partly genetically determined. TT performance was improved by 3.5%, which can be explained by the equal improvement in MAP. Due to measurement variability for the O_2-analyzer, all VO_{2max} changes smaller than 3% might reflect measurement variability and not actual changes in VO_{2max} (20).

Even though the HIIT block was performed as solely up-hill running, all athletes that improved VO_{2max} in running also improved VO_{2max} in cycling. This finding is also in accordance with the case previously reported in Støren et al. (18). The transferability from running to cycling points at predominately O_2 supply rather than O_2 demand adaptations i.e. adaptations to stroke volume (11). However, we cannot exclude the possibility that there might have been individual differences in the adaptations in cycling to the training performed as running. This may partly explain the larger inter-individual differences in VO_{2max} than in TT performance.

Previous studies have shown the effectiveness of HIIT in improving endurance performance, but a need for a larger volume of HIIT in order to improve further from a high baseline level (4, 11, 18, 19). The three athletes with the lowest baseline VO_{2max} were all between 50 and 60 $ml \cdot kg^{-1} \cdot min^{-1}$. Two of these improved VO_{2max} from pre-test to post-test while one remained unchanged. The four athletes with the highest baseline VO_{2max} were all between 65 and 70 $ml \cdot kg^{-1} \cdot min^{-1}$. Three of these decreased VO_{2max} from pre-test to post-test, while one improved. We may speculate that some of the athletes with the highest baseline values actually had insufficient training load during the period, although there is also a possibility for acute over-reaching (5). If insufficient training load among those with the highest baseline VO_{2max} was the case, it would be in accordance with Støren et al (19) showing a negative correlation between baseline VO_{2max} and Δ VO_{2max} in untrained and moderately trained. However, the heterogeneity of the participants in Støren et al (19) regarding baseline values and training background vastly exceed that of the present study. The participants in the present study were all very well trained, with a weekly amount of training ranging from approximately 15 to 20 hours. None of the cyclists reported tiredness or other over-reaching symptoms during the period when asked for this, which does not point at over-reaching. Actually, on a scale from 1-10, all athletes scored from 1-4 indicating no or little muscle soreness. On the other hand, although all of the athletes managed to increase HR to their target HR in all training sessions, five of the seven cyclists found this demanding in the last two to four sessions. However, among these five cyclists, three improved and two decreased their VO_{2max}. Also, one of the athletes who decreased VO_{2max} by 3.2% form pre- to post-test performed a new VO_{2max} test one week after the post-test. The extra week only included short sessions of low intensity training. This athlete then improved VO_{2max} by 5.7% (2.5% compared to pre-test). The latter actually does point at over-reaching. The correlation between baseline VO_{2max} and ΔVO_{2max} was moderate, yet not statistically significant. This is probably due to a low number of participants; hence, it is of interest that future studies examine potential for improvement based on initial training and fitness status. Although changes in body weight was within normal day-to-day variation, and the athletes were encouraged to have the same diet 24 hours prior to each test, we cannot exclude that small variations in diet composition or nutritional status on macro- or micronutrient level may have affected the performance (14). Other possible explanations for the large inter-individual responses, which unfortunately have not been measured in this study, might be related to exercise genomics (3), sleeping patterns and quality (21), and psychosocial factors including family life (17). For the female participants, we cannot exclude the possibility that their TT performance was affected by their menstrual cycles as this may affect recovery from training (9).

The large inter-individual responses to a block of HIIT call for tailoring of the training and close monitoring of biological and psychological responses in each athlete, especially since it seems difficult to predict the level of adaptations even in a rather homogenous cohort of very well-trained athletes as shown in the present study. Although there were too few participants to explore possible sex differences in the responses, future research should aim to evaluate this possibility. Future studies should also provide longer follow-up to evaluate time needed for the athletes to reach a potential super compensation phase.

To conclude, a block of 14 HIIT session in nine days provided in average unchanged VO_{2max} and 3.4% improved TT performance 7 days after finishing the intervention, but with large inter-individual variations among the athletes.

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