Effects of submaximal and supramaximal interval training on determinants of endurance performance in endurance athletes

M. Paquette1,2, O. Le Blanc1,2, S. J. E. Lucas3,4, G. Thibault1, D. M. Bailey5,6, P. Brassard1,2

1Department of Kinesiology, Faculty of Medicine, Université Laval, Québec, QC, Canada, 2Research Center of the Institut Universitaire de Cardiologie et de Pneumologie de Québec, Québec, QC, Canada, 3School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Birmingham, UK, 4Department of Physiology, University of Otago, Dunedin, New Zealand, 5Neurovascular Research, Laboratory, Faculty of Life Sciences and Education, University of South Wales, South Wales, UK, 6Sondes Moléculaires en Biologie, Laboratoire Chimie Provence UMR 6264 CNRS, Université de Provence Marseille, Marseille, France

Corresponding author: Patrice Brassard, PhD, Department of Kinesiology, Faculty of Medicine, PEPS – Université Laval, 2300 rue de la Terasse, room 2122, Québec, QC, Canada G1V OA6. Tel.: 418 656-2131 (5621), Fax: 418-656-4908, E-mail: patrice.brassard@kin.ulaval.ca

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We compared the effects of submaximal and supramaximal cycling interval training on determinants of exercise performance in moderately endurance-trained men. Maximal oxygen consumption (VO2max), peak power output (Ppeak), and peak and mean anaerobic power were measured before and after 6 weeks (3 sessions/week) of submaximal (85% maximal aerobic power [MP], HIIT85, n = 8) or supramaximal (115% MP, HIIT115, n = 9) interval training to exhaustion in moderately endurance-trained men. High-intensity training volume was 47% lower in HIIT115 vs HIIT85 (304 ± 77 vs 571 ± 200 min; P < 0.01). Exercise training was generally associated with increased VO2max (HIIT85: +3.3 ± 3.1 mL/kg/min; HIIT115: +3.3 ± 3.6 mL/kg/min; Time effect P = 0.002; Group effect: P = 0.95), Ppeak (HIIT85: +18 ± 9 W; HIIT115: +16 ± 27 W; Time effect P = 0.045; Group effect: P = 0.49), and mean anaerobic power (HIIT85: +0.42 ± 0.69 W/kg; HIIT115: +0.55 ± 0.65 W/kg; Time effect P = 0.01; Group effect: P = 0.18). Six weeks of submaximal and supramaximal interval training performed to exhaustion seems to equally improve VO2max and anaerobic power in endurance-trained men, despite half the accumulated time spent at the target intensity.

In endurance sports such as cycling, maximal oxygen consumption (VO2max), endurance capacity, anaerobic fitness, and movement efficiency are important determinants of endurance performance (Joyner & Coyle, 2008). Evidence strongly suggests that both high-volume, low-intensity and low-volume, high-intensity training (Londeree, 1997; Buchheit & Laursen, 2013) are important in order to optimize adaptations in endurance athletes (Stöggel & Sperlich, 2014). High-intensity training, although representing a smaller proportion of athletes’ training volume, is a critical component in the training of all successful endurance athletes (Seiler, 2010). High-intensity training is usually performed using interval training, which involves repeated short-to-long bouts of rather high-intensity exercise interspersed with recovery periods (Buchheit & Laursen, 2013). Various high-intensity interval training (HIIT) protocols are utilized in athletes’ training programs, including submaximal training (below VO2max), VO2max training, and supramaximal training (superior power output to that produced at VO2max); thus, the optimal exercise training stimulus remains equivocal.

Submaximal interval training can improve endurance performance in highly endurance-trained cyclists (Westgarth-Taylor et al., 1997; Kristoffersen et al., 2014; Stöggel & Sperlich, 2014). Accumulating evidence indicates that supramaximal interval training can also increase maximal aerobic capacity in moderately active adults (Rodas et al., 2000; Gist et al., 2014; Weston et al., 2014), although the beneficial impact of interval training in that intensity domain remains ambiguous in athletic men maintaining usual low-intensity base-training (Weston et al., 2014).

Few studies have directly compared submaximal, maximal, and supramaximal interval training in endurance-trained athletes (Stepto et al., 1999; Laursen et al., 2002; Esfarjani & Laursen, 2007), and those that have report equivocal findings. For example, Stepto et al. (1999) reported greatest improvements in cycling endurance performance following...
six HIIT sessions over 3 weeks performed at 85% peak power (P_{peak}, i.e., submaximal interval training) and 175% P_{peak} (i.e., supramaximal interval training), compared to HIIT performed at 80%, 90%, or 95% P_{peak}. In contrast, others report that interval training at VO_{2max} performed twice a week for 4 weeks (Laursen et al., 2002) or 10 weeks (Esfarjani & Laursen, 2007) shows larger beneficial effects on performance and key physiological determinants of performance (e.g., VO2max and 3000 m running time) in trained athletes compared to supramaximal interval training at 130% of maximal aerobic speed (Laursen et al., 2002; Esfarjani & Laursen, 2007) and 175% P_{peak} (Laursen et al., 2002; Esfarjani & Laursen, 2007). Furthermore, 6 weeks of supramaximal running interval training (3 sessions/week at 130% 3000-m running speed) provided greater benefits for endurance, sprint, and repeated sprint performance than submaximal interval training (at 3000-m running speed) in physically active but not endurance-trained individuals (Cicioni-Kolsky et al., 2013). Accordingly, whether submaximal or supramaximal interval training elicits the greatest benefits in endurance-trained athletes remains uncertain.

Most studies comparing different training intensities usually match sessions based on achieving the same energy consumption across interventions. However, Seiler et al. (2013) has suggested that matching training regimens on energy consumption induces different overall effort between interval regimens, with total effort or fatigue being lower when energy expenditure is achieved with lower intensity exercise. Importantly, as pointed out by Seiler et al. (2013) and Ronnestad et al. (2015), athletes match their HIIT sessions for overall effort and accumulated fatigue in real life situations, not for total work. Thus, effort matching appears a more valid way to compare intensities, as they would be used in real-world settings.

Therefore, the aim of this study was to assess the impact of effort-matched submaximal and supramaximal interval training on determinants of endurance performance in moderately endurance-trained adults. We hypothesized that, notwithstanding a lower training volume, supramaximal interval training would increase to a greater extent aerobic capacity compared to submaximal interval training. We also expected an improvement in anaerobic capacity following supramaximal, but not submaximal interval training.

**Methods**

**Participants**

Nineteen moderately endurance-trained men (27 ± 7 years, 72 ± 10 kg), with a training history of 5 to 12 h/week for at least 2 years, volunteered to participate in this study. Participants were road cyclists (n = 9), triathletes (n = 7), mountain bikers (n = 2), and a cross-country skier, who were training 8.4 ± 2.7 h/week in the month before the study, and were taking part in to 2 interval training sessions/week (0.5 ± 0.7 HIIT sessions/week on average). This study was approved by the local ethics committee and was conducted in accordance to the principles established in the Declaration of Helsinki, with verbal and written informed consent provided by all participants.

**Experimental design**

Participants reported to the laboratory on four separate occasions over a period of 2 weeks to perform: (a) anthropometric and resting measurements, (b) an incremental cycling test to determine VO_{2max} and P_{peak}; (c) a maximal aerobic power (MP) stepwise intermittent protocol, and (d) a 30-s Wingate test to assess sprint performance (peak and mean anaerobic power). Participants were asked to refrain from training for at least 12 h and to avoid alcohol and caffeine consumption for 24 h before each visit. All sessions were performed in the same order for all participants and there was at least 24 h between testing sessions. After these four preliminary evaluation sessions, participants were matched according to their age and VO_{2max} before one from each pair was randomly assigned to one of two training groups: submaximal (HIIT_{85}) or supramaximal (HIIT_{115}). By study design, participants in both groups had similar age (HIIT_{85}: 26 ± 6 years, HIIT_{115}: 27 ± 6 years), height (HIIT_{85}: 1.77 ± 0.08, HIIT_{115}: 1.78 ± 0.08 m), body mass, % body fat, and VO_{2max} (Tables 1 and 2). The four evaluation sessions were repeated 48–96 h following the end of a 6-week training program (see Fig. 1).

**Training interventions**

Training consisted of three HIIT sessions per week over a period of 6 weeks, with 48–72 h between sessions. On remaining days, participants were asked to avoid high-intensity exercise, but to maintain a similar low and/or moderate intensity training volume typically performed prior to the study. The HIIT_{85} group performed repeated 1–to 7-min effort bouts, depending on the session, at 85% MP, separated by half the effort time of active recovery (150 W or 50% MP if MP <300 W) until exhaustion. The HIIT_{115} group performed repeated 30-s to 1-min effort bouts, depending on the session, at 115% MP, separated by twice the effort time of active recovery (150 W or 50% MP if MP <300 W) until exhaustion. Table 3 outlines the 18 sessions performed in a randomized order during the 6 weeks by participants from HIIT_{85} and HIIT_{115} groups. The reasons for alternating exercise bout duration from one session to another throughout the 6-week training period in both groups were to reduce monotony of exercise training and to focus on exercise intensity, e.g., 85 vs 115% MP, and not exercise duration. Trainings were performed on Tacx Bushido trainers (T tacx, Terneuzen, The Netherlands).

HIIT_{85} and HIIT_{115} protocols were matched for total effort rather than for total work, which is closer to what athletes typically do when performing hard interval sessions at various intensities (Seiler et al., 2013). Accordingly, a number of repetitions was not specifically prescribed for each participant, but they rather had to keep alternating effort bouts at either 115% or 85% MP and resting periods until exhaustion, defined as the inability to complete an effort bout (Table 3). Session rate of perceived exertion (RPE; 0-10 scale) was obtained within 10 min after the end of each training session (Foster, 1998). After 3 weeks of training, participants' MP...
was measured, using the same protocol as in the preliminary evaluation, to adjust training intensity for the 3 remaining weeks. Total HIIT volume was calculated for each participant, using the number of repetitions performed and the length of the effort bouts of every session. Work performed was also calculated for each training session. Total work included both effort and recovery bouts, while total HIIT work included only effort bouts. Calculation did not include warm-up and cool down, which were similar between groups.

**Methodology**

**Anthropometric measurements and resting hemodynamics**

Stature and body mass were measured in each participant. Lean mass and % body fat were assessed using bioelectrical impedance (InBody520, Biospace, California, USA). Participants then rested supine for 10 min. Heart rate (HR; ECG monitoring) and arterial pressure using photoplethysmography (Wescaling et al., 1993) (Nexfin, Edwards Lifesciences, Ontario, Canada) were continuously monitored on a beat-by-beat basis during the resting period, and the last 5 min of recording was averaged and taken as the baseline.

**Maximal oxygen consumption (VO₂max)**

The maximal rate of oxygen consumption (VO₂max) was determined using an incremental cycling test performed on an electromagnetically braked upright cycle ergometer (Lode Excalibur, Groningen, Netherlands). VO₂max was defined as the highest value of oxygen consumption during the incremental test or the highest value during the last 5 min of the sub-maximal test. The ventilatory threshold (VT) was defined as the point at which the slope of VO₂ increase exceeded the slope of ventilation increase. The respiratory exchange ratio (RER) was calculated as the ratio of CO₂ production to O₂ consumption. Heart rate (HR) and respiratory rate (RR) were monitored throughout the tests. Blood pressure (BP) was measured using a sphygmomanometer. Heart rate variability (HRV) was measured using heart rate variability monitoring system (Polar, Kempele, Finland).

**Table 1. Resting measurements pre- and post-training**

<table>
<thead>
<tr>
<th>Group</th>
<th>HIIT₈₅ (n = 8)</th>
<th>HIIT₁₁₅ (n = 9)</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>72.1 ± 12.0</td>
<td>71.7 ± 12.0</td>
<td>73.1 ± 7.5</td>
</tr>
<tr>
<td>%Body fat (%)</td>
<td>13.4 ± 4.9</td>
<td>12.9 ± 4.0</td>
<td>11.5 ± 6.0</td>
</tr>
<tr>
<td>Lean mass (kg)</td>
<td>62.4 ± 10.7</td>
<td>62.5 ± 10.9</td>
<td>64.5 ± 5.6</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>115 ± 15</td>
<td>112 ± 10</td>
<td>116 ± 12</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>66 ± 7</td>
<td>63 ± 6</td>
<td>65 ± 6</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>56 ± 8</td>
<td>51 ± 7</td>
<td>54 ± 8</td>
</tr>
</tbody>
</table>

Values are mean ± SD; HIIT₈₅, Submaximal training group; HIIT₁₁₅, Supramaximal training group; *Significant difference (P < 0.05) BP, blood pressure.

**Table 2. Determinants of endurance performance adaptations to the 6-week HIIT**

<table>
<thead>
<tr>
<th>Group</th>
<th>HIIT₈₅ (n = 8)</th>
<th>HIIT₁₁₅ (n = 9)</th>
<th>P-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Incremental exercise protocol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VT (L/min)</td>
<td>2.06 ± 0.39</td>
<td>2.24 ± 0.55</td>
<td>2.07 ± 0.38</td>
</tr>
<tr>
<td>RCP (L/min)</td>
<td>3.54 ± 0.53</td>
<td>3.80 ± 0.51</td>
<td>3.48 ± 0.34</td>
</tr>
<tr>
<td>Ppeak (W)</td>
<td>381 ± 46</td>
<td>399 ± 54</td>
<td>397 ± 39</td>
</tr>
<tr>
<td>VO₂max (L/min)</td>
<td>3.99 ± 0.63</td>
<td>4.21 ± 0.63</td>
<td>4.01 ± 0.53</td>
</tr>
<tr>
<td>VO₂max (ml/kg/min)</td>
<td>56.0 ± 6.0</td>
<td>59.3 ± 4.7</td>
<td>55.9 ± 4.0</td>
</tr>
<tr>
<td>HRmax (bpm)</td>
<td>193 ± 6</td>
<td>191 ± 7</td>
<td>188 ± 8</td>
</tr>
<tr>
<td>SBPmax (mmHg)</td>
<td>207 ± 20</td>
<td>205 ± 32</td>
<td>212 ± 33</td>
</tr>
<tr>
<td>DBPmax (mmHg)</td>
<td>81 ± 8</td>
<td>78 ± 6</td>
<td>78 ± 8</td>
</tr>
<tr>
<td>RRmax (breath/min)</td>
<td>49 ± 11</td>
<td>52 ± 9</td>
<td>54 ± 10</td>
</tr>
<tr>
<td>RER</td>
<td>1.39 ± 0.09</td>
<td>1.35 ± 0.10</td>
<td>1.38 ± 0.10</td>
</tr>
<tr>
<td>MP test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MP (W)</td>
<td>310 ± 51</td>
<td>315 ± 55</td>
<td>316 ± 44</td>
</tr>
<tr>
<td>Tₛₘₛ (min)</td>
<td>10.3 ± 3.8</td>
<td>13.7 ± 4.1</td>
<td>11.4 ± 4.1</td>
</tr>
<tr>
<td>Cycling efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GME (%)</td>
<td>21.5 ± 0.6</td>
<td>20.9 ± 1.0</td>
<td>19.6 ± 1.1</td>
</tr>
<tr>
<td>Sprint performance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak anaerobic power (W/kg)</td>
<td>15.5 ± 0.8</td>
<td>15.9 ± 1.8</td>
<td>16.6 ± 0.9</td>
</tr>
<tr>
<td>Mean anaerobic power (W/kg)</td>
<td>10.0 ± 0.5</td>
<td>10.4 ± 0.5</td>
<td>10.3 ± 0.7</td>
</tr>
</tbody>
</table>

Values are mean ± SD; HIIT₈₅, Submaximal training group; HIIT₁₁₅, Supramaximal training group; VO₂max, maximal oxygen consumption, Ppeak, peak power output during the ramp exercise protocol, HR, heart rate, RER, respiratory exchange ratio, RR, respiration rate, VT, ventilatory threshold, RCP, respiratory compensation point, MP, maximal aerobic power, Tₛₘₛ, time to exhaustion in MP test, GME, gross mechanical efficiency; Significant difference (P < 0.05).
cycle ergometer (Corival, Lode, the Netherlands). The test started with 1 min of unloaded pedaling followed by an incremental ramp protocol (30 W/min) to volitional exhaustion. Expired air was continuously recorded using a breath-by-breath gas analyzer (Breezesuite, MedGraphics Corp., Minnesota, Saint Paul, USA) for determination of VO₂, carbon dioxide production (VCO₂), and respiratory exchange ratio (RER: VCO₂/VO₂). Heart rate (HR) was obtained from ECG monitoring and arterial pressure was measured at rest and every 2 min during the test using an automated sphygmomanometer with a headphone circuit option (Model 412, Quinton Instrument, Bothell, Washington, USA). Maximal VO₂ was defined as the highest 30-s averaged VO₂, concurrent with a RER ≥1.15. Peak power (i.e., Ppeak) was the highest power output achieved during the test and maximal HR (HRmax), respiratory rate (RRmax), and RER (RERmax) were defined as the highest values recorded during the test. The ventilatory threshold (VT) was manually determined using the V-slope method (Beaver et al., 1986). The respiratory compensation point (RCP) was determined using the criterion of an increase in ventilatory equivalents for O₂ and CO₂ concomitant to a decrease in end-tidal partial pressure of CO₂ (Wasserman et al., 1999).

Maximal aerobic power (MP)

Training intensity was set relative to participants’ MP in this study. In order to determine the power output of the first stage of the MP test, predicted MP (MPp) was calculated from the VO₂max reached during the incremental cycling test using the following equation:

\[
VO₂(\text{mL/min}) = \left(\frac{\text{power output [W]} \times 6\text{kpm/W}}{2\text{ml/kpm} + 300}\right) \text{ (ACSM, 2000)}
\]

Therefore:

\[
\text{MP}_p(\text{W}) = \frac{(\text{VO}_2^{\text{max}}(\text{mL/min}) - 300)/12}{\text{MP}}
\]

Participants performed the MP test on the same cycle ergometer as the incremental cycling test. After a 10-min warm-up (first 5 min: 50% MPp or 150 W, last 5 min: 5% MPp or 15 W increase in power output every minute), an intermittent test with 5-min stages was used (see Fig. 2). Cadence was freely chosen throughout the test. MP was defined as the power output of the last completed stage or the power output of an uncompleted stage, where VO₂ increased by >150 mL/min compared to the previous completed stage. The accumulated time of exercise (excluding warm-up and recovery phases) during the MP test (TMP) was used as an index of endurance. VO₂, HR, and arterial pressure were monitored as previously described during the incremental cycling test.
Cycling efficiency

Gross mechanical efficiency (GME, %) was used to assess cycling efficiency. GME was defined as the ratio of mechanical work output to energy input (Barbeau et al., 1993), where:

\[
\text{Mechanical work output (kgm)} = \frac{\text{power output (W)}}{\text{time (sec)}} \times 0.102 \text{kgm/j}
\]

and:

\[
\text{Energy input (kgm)} = \frac{\text{VO}_2(\text{L/min}) \times 4.838 \text{kcal/L}}{\text{(thermal equivalent)}} \times 426.4 \text{kgm/kcal}
\]

For calculation of GME, data were collected during the fifth min of the warm-up during the MP test.

Sprint performance

Peak and mean anaerobic power were assessed using a 30-s Wingate Anaerobic test. The test was performed on an electronic cycle ergometer (Velotron, RacerMate, Seattle, Washington, USA). Before the test, participants performed a 10-min warm-up at 150 W or 50% MP (for participants with a MP ≤ 300 W) with 5-s non-maximal sprints every min during the last 5 min. Participants were allowed a 2-min resting period before starting the test. The test was preceded by a 2-s unloaded acceleration. The load was then set at 9.4% of participants’ body mass, and participants were asked to attain a peak power as quickly as possible and to continue to exercise maximally for the duration of the sprint (30 s), while remaining seated. Peak anaerobic power (peak power/body weight) and mean anaerobic power (mean power/body weight) were calculated.

Statistical analysis

After confirmation of distribution normality using Shapiro–Wilks normality tests, between-group differences (training characteristics) were analyzed using independent samples t-tests. For the remaining variables, between-group differences were analyzed using a two-way (Time: Pre vs Post × Group: HIIT85 vs HIIT115) repeated measures analysis of variance (ANOVA). Following an interaction effect (Time × Group), differences were located using paired (within groups) and independent (between groups) samples t-tests, with Bonferroni correction. Significance was established at \( P < 0.05 \) and data expressed as mean ± standard deviation.

Results

Participant compliance

Data from one participant in HIIT85 were removed from analysis due to illness and absence for more than three training sessions. Data from one participant in HIIT115 were removed from analysis due to excessive fatigue during the training regime. Therefore, eight participants from HIIT85 and nine participants from HIIT115 completed the study.

Training characteristics

High-intensity training volume was 47% less in HIIT115 than HIIT85 (19.3 ± 4.7 vs 36.6 ± 14.4 min/session; \( P = 0.005 \)). Total work performed during each session was 741 ± 317 kJ for HIIT115 and 759 ± 200 kJ for HIIT85 (\( P = 0.89 \)) when considering effort and recovery bouts, or 585 ± 260 kJ for HIIT115 and 421 ± 114 kJ for HIIT85 (\( P = 0.11 \)) when considering only effort bouts. Participants from both groups attended an average of 16 ± 1 training sessions during the 6 weeks (HIIT85 vs HIIT115: \( P = 0.79 \)). Sessions RPE averaged 9.5 ± 0.3 for HIIT85 (range: from 8 to 10) and 9.3 ± 0.6 for HIIT115 (range: from 5 to 10) (\( P = 0.50 \)).

Anthropometric measurements and resting hemodynamics

Body composition measures were not affected by either HIIT training program (Table 1). Resting HR following both training programs was lowered (interaction, \( P = 0.10 \); time effect, \( P < 0.01 \)); whereas HIIT training intensity differentially influenced resting DBP and SBP measures, although clear statistical significance was only observed with DBP (Table 1).
Determinants of exercise performance

**Incremental cycling exercise to exhaustion**

Irrespective of intensity (all interactions, $P > 0.05$), training increased VT, RCP, $P_{\text{peak}}$, and VO$_{2\text{max}}$ but decreased maximal DBP (Table 2 and Fig. 3). The other variables measured during the incremental test remained unchanged following training (Table 2).

**Fig. 3.** Individual training responses for peak power output (A) VO$_{2\text{max}}$ (B: ml/kg/min; C: L/min) and peak (D) and mean anaerobic power (E) in participants from HIIT$_{85}$ and HIIT$_{115}$ groups. Values are mean ± SEM. VO$_{2\text{max}}$, maximal oxygen consumption.
Mean aerobic power (MP)

Similar increases in MP and \( T_{\text{MP}} \) were observed following both HIIT training programs (Table 2).

Cycling efficiency

GME for participants in the HIIT\(_{85}\) group was higher than the HIIT\(_{115}\) group at both pre- and post-training. While on average GME decreased more in the HIIT\(_{85}\) than the HIIT\(_{115}\) group following training, this did not reach significance (interaction \( P = 0.36 \) nor did the pooled effect \( P = 0.06 \)). Mean cadence during GME assessment was similar between evaluation sessions.

Sprint performance

Training increased mean anaerobic power irrespective of training intensity, whereas peak anaerobic power tended to increase following training (Table 2).

Discussion

The primary novel finding associated with the present study was that supramaximal interval training was equally effective compared to effort-matched submaximal interval training given that identical improvements in \( \text{VO}_2\text{max} \) and anaerobic power were observed despite half the accumulated time spent at the target intensity.

Submaximal and maximal performance

Results from recent studies suggesting the effectiveness of supramaximal interval training for improving \( \text{VO}_2\text{max} \) and submaximal endurance capacity (Rodas et al., 2000; Burgomaster et al., 2005; Gist et al., 2014; Weston et al., 2014) raise the question: is supramaximal HIIT more efficient than submaximal HIIT in improving submaximal and maximal aerobic performance? Our findings suggest that supramaximal HIIT is more time-efficient than submaximal HIIT in improving \( \text{VO}_2\text{max} \), as training at 115% MP for ~19 min/session induced the same improvements in \( \text{VO}_2\text{max} \) as training at 85% MP for ~37 min/session, indicating that an increase in training intensity compensates for the decrease in total work duration. These results are supported by those of a recent study (Rønnestad et al., 2015) revealing that 10 weeks of supramaximal interval training (30-s work intervals separated by 15-s recovery for 9.5 min) is superior to effort-matched submaximal interval training (4 x 5 min work intervals separated by 2.5-min recovery periods) of similar total training duration on several endurance and performance measurements in trained cyclists. These results suggest that supramaximal interval training is at least as effective as more traditional submaximal interval training to increase \( \text{VO}_2\text{max} \) and endurance performance in moderately trained men.

Supramaximal performance

Improvements in anaerobic fitness have previously been associated with enhancements in endurance performance (Bulbulian et al., 1986; Weston et al., 1997); for example, anaerobic fitness has been found to predict endurance performance in cross-country mountain biking (Inoue et al., 2012), cross-country skiing (Staib et al., 2000), and track endurance cycling (Craig et al., 1993). Findings from the present study indicate that both submaximal and supramaximal HIIT training can be advantageous for endurance athletes as it increases anaerobic fitness (as characterized by mean anaerobic power during a 30-s cycling sprint).

In the present study, HIIT was not associated with an improvement in cycling efficiency. Cycling efficiency is related to endurance performance, as cyclists with a higher efficiency can generate a greater power output for the same \( \text{VO}_2 \) (Coyle et al., 1992). GME has been reported to be in the range of 18–23% (Coyle et al., 1992), which is in line with our results. Previous studies have shown that HIIT performed at an intensity above onset of blood lactate accumulation (Hopker et al., 2010) and strength training (Sunde et al., 2010) can slightly improve cycling efficiency in competitive cyclists. Freely chosen cadence and accumulated fatigue after the training protocol may explain our results, as both cadence and fatigue alter GME (Chavarren & Calbet, 1999; Millet et al., 2000).

There are some limitations to our study that need to be addressed. Without a performance test (i.e., a time-trial) it is difficult to state which of the two training interventions will further improve endurance performance. However, the aim of the present study was to assess the impact of the two training intensities on important determinants of endurance performance and not performance per se. Furthermore, our participants were moderately endurance-trained men and therefore our results cannot necessarily be extended to women, healthy or diseased, or high-performance athletes. We also acknowledge that the small sample size of our study is associated with interpretive limitations, although a retrospective power analysis revealed that we were adequately powered to detect main effects with values exceeding 0.8 at \( P < 0.05 \) for the main determinants of exercise performance examined in this study.

In summary, these findings suggest that both submaximal and supramaximal interval training,
performed to exhaustion three times a week for 6 weeks, can equally improve VO_{2\text{max}} and anaerobic power in endurance-trained men despite half the accumulated time spent at the target intensity. These results may alternatively imply that submaximal interval training is just as effective as supramaximal training to enhance these physiological indices of performance, while avoiding both physiological and psychological stress that accompany supramaximal training programs.

**Perspectives**

The results of this study provide an answer to a question raised by the growing interest of researchers, coaches, and athletes toward supramaximal interval training: Is effort-matched submaximal and supramaximal interval training equally efficient in improving determinants of endurance performance in endurance-trained men? It appears that both submaximal and supramaximal interval training, performed to exhaustion three times a week for 6 weeks, can equally improve VO_{2\text{max}} and anaerobic power in these moderately trained athletes. Further research is needed to assess the impact of long-term submaximal and supramaximal training as well as the effect of combining both types of training in the same period or in consecutive training blocks on endurance performance.

**Key words:** Aerobic capacity, sprint performance, endurance training, cycling.

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