The inclusion of sprints in low-intensity sessions during the transition period of elite cyclists improves endurance performance 6 weeks into the subsequent preparatory period

Madison Taylor*[1], Nicki Almquist*[2], Bent Rønnestad[2], Arnt Erik Tjønna[3,6], Morten Kristoffersen[4], Matt Spencer[5], Øyvind Sandbakk[1] and Knut Skovereng[1].

Original Investigation

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[1] Centre for Elite Sports Research, Department of Neuromedicine and Movement Science, Norwegian University of Science and Technology, Trondheim, Norway

[2] Department of Health and Exercise Physiology, Faculty of Health and Social Sciences, Inland University College, Lillehammer, Norway

[3] Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, Trondheim, Norway

[4] Department of Sport, Diet and Natural Sciences, Western Norway University of Applied Sciences, Bergen, Norway

[5] Department of Public Health, Sport and Nutrition, University of Agder, Agder, Norway

[6] *NeXt Move* core facility at Faculty of Medicine, Norwegian University of Science and Technology, Trondheim, Norway and Central Norway Regional Health Authority.

**the authors contributed equally to the manuscript*

Corresponding Author

Knut Skovereng
Department of Neuromedicine and Movement Science
Norwegian University of Science and Technology
7491 Trondheim, Norway
E-mail: knut.skovereng@ntnu.no
Phone: +47 99579355

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Abstract

***Purpose*:** To investigate the effects of including repeated sprints in a weekly low-intensity (LIT)-session during a 3-week transition period on cycling performance 6 weeks into the subsequent preparatory period in elite cyclists.

***Methods*:** Eleven elite male cyclists (age: 22.0 [3.8]y, body mass: 73.0 [5.8]kg, height: 186 [7]cm, maximal oxygen uptake (VO_{2max}): 5469 [384] $mL \cdot min^{-1}$) reduced their training load by 64% and performed only LIT-sessions (CON, n=6), or included 3 sets of 3 x 30-sec maximal sprints in a weekly LIT-session (SPR, n=5) during a 3-week transition period. There were no differences in training load leading up to the transition period, in the reduction during the transition period or in the increase in the preparatory period between groups. Physiological and performance measures were compared between the end of the competitive period (COMP) and 6 weeks into the subsequent preparatory period (PREP).

***Results*:** SPR demonstrated a 7.3% [7.2%] improvement in mean power output during a 20-min all-out test ($W \cdot kg^{-1}$) at PREP, which was greater than CON (-1.3% [4.6%]) (p=0.048). SPR had a corresponding 7.0 [3.6]% improvement in average VO_2 during the 20-min all-out test, which was larger than the 0.7 [6.0]% change in CON (p=0.042). No change in VO_{2max}, gross efficiency or power output at blood lactate concentration of 4 $mmol \cdot L^{-1}$ from COMP to PREP occurred in either group.

***Conclusion*:** The inclusion of sprints in a weekly low-intensity (LIT)-session during the transition period of elite cyclists provided a performance advantage 6 weeks into the subsequent preparatory period, which coincided with a higher performance-VO_2.

Keywords: cycling performance, training load, maximal sprint, performance-VO_2, iTrimp

Introduction

The annual training season of a competitive cyclist is often broken into three periods; a competitive-, transition- and preparatory period.[1] The competitive period generally runs from April through to the end of September, during which the cyclist must achieve and maintain peak physical fitness and performance, accumulating up to 90 days of competition.[1,2] Following the competitive period, cyclists are encouraged to take 3-5 weeks of rest to promote recovery during the transition period. During this period training volumes are decreased by 60-80% and almost exclusively low intensity training (LIT) is performed.[2-4] Several authors have reported a decline in endurance performance and/or performance-determining factors following the transition period of trained cyclists.[3-6] The subsequent preparatory period is consequently used to regain lost adaptations and improve performance leading up to the next competitive period.[1]

Maintaining endurance performance during the transition period has previously been argued as crucial for elite cyclists to be able to improve competition performance later in the season.[7] Rønnestad et al.[8] showed that the inclusion of a weekly high-intensity (HIT) session during an 8-week long transition period allowed well-trained cyclists to maintain key physiological adaptations following the transition period and improved endurance performance 16 weeks into the subsequent preparatory period. In contrast, a control group who only trained LIT experienced a physiological decline during the transition period and were unable to improve their endurance performance in the subsequent preparatory period. Additionally, Mallol et al[9] showed that a 4-week HIT intervention could improve maximal oxygen uptake (VO_{2max}) and maintain cycling performance in a group of trained triathletes even when total training duration was decreased by 44%. These findings suggest that the inclusion of an intensive stimulus is important for the maintenance of performance-determining physiological adaptations and may therefore provide athletes with a performance advantage in the subsequent training period. However, HIT-sessions are very strenuous and are often reduced to a minimum by elite cyclists in the transition period.[3-5,10] Previous research suggests that sprints could be an easier strategy for maintaining endurance performance in periods of reduced training volume.[11,12] Indeed, 30-sec sprints have repeatedly been shown to improve anerobic power and aerobic endurance performance in well-trained endurance athletes,[11-16] offering a high intensity stimulus in a short amount of time. Additionally, short HIT intervals are perceived to be easier than longer HIT-intervals[10] and require a reduced time commitment.[15,17] Therefore, an intriguing alternative for maintaining an intensive stimulus during the transition period could be to include a weekly session of short, repeated 30-sec sprints during the transition period.

Sprinting is an important feature of competitive cycling. Power output (PO) varies dramatically throughout a race, repeatedly requiring riders to produce short-duration bursts of maximal power for climbing, breakaways, race starts and finishes. [2,18] In fact, races are often won or lost with a sprint finish. Many competitive cyclists already use sprints to complement their endurance training in order to improve race performance and sprint power.[18] This training strategy consistently demonstrates positive effects on cycling performance variables such as improved sprint ability and mean PO during a 40-min out all time-trial.[16,19,20] Additionally, sprint training has been showed to maintain endurance performance in runners during a 4-week period of reduced training.[12] However, the current research on sprint training has not focused on elite cyclists and whether the inclusion of sprints during the transition period could lead to improved performance in the subsequent preparatory period has yet to be investigated.

The primary aim of the current study was to investigate the effect of including sprints in a weekly LIT-session during a 3-week transition period on cycling performance, performance-determining physiological factors and repeated sprint-ability 6 weeks into the subsequent preparatory period in elite cyclists. We hypothesized that the inclusion of sprints would lead to superior endurance and sprint performance in the subsequent preparation period.

Methods

This study is part of a multicenter, multiphase study conducted at four Norwegian universities with the same laboratory equipment and testing procedures. The responses to the 3-week transition period in a larger sample of athletes is reported elsewhere.[21] Specific data from our sample is provided in Supplementary Table 1.

Participants

Twenty-one elite male cyclists volunteered for this study. A subset of thirteen cyclists were monitored for an additional 6 weeks into the subsequent preparatory period following the initial 3-week intervention. Two participants were excluded, one for failure to comply with the retraining protocol and one due to injury, thus 11 participants were included in final analysis (Table 1). Based on the physiological characteristics suggested by De Pauw et al.,[22] 7 participants were regarded as level 5 athletes (VO_{2max} >71 $mL\cdot kg^{-1}\cdot min^{-1}$, maximal aerobic power output (W_{max}): >5.5 $W\cdot kg^{-1}$), and 4 participants were regarded as level 4 athletes (VO_{2max}: 65-71 $mL\cdot kg^{-1}\cdot min^{-1}$, W_{max}: 4.9-6.4 $W\cdot kg^{-1}$), henceforth referred to as elite cyclists. Participants were informed of the risks of participating in this study prior to the first test and provided written informed consent. The study was performed according to the ethical standards established by the Helsinki Declaration of 1976, approved by the Norwegian Social Science Data Service (NSD) and the local committee at Lillehammer University College.

Table 1

Design

The present study included two test periods (Figure 1). An initial performance test was completed 3-5 days after each cyclists' last competitive race of the season (COMP). The participants were randomly assigned to the sprint training group (SPR) or low intensity group (CON). There were no statistically significant differences in average weekly training load ($iTrimp\cdot wk^{-1}$), training time ($hrs\cdot wk^{-1}$) or intensity distribution between the groups during the final 4 weeks of the competitive period. During the 3-week transition period, both groups were instructed to perform low-volume LIT, while SPR included three supervised sessions (once per week) where sprints were included in LIT-sessions. The 90-min session included a 20-min warm up at 60% of VO_{2max}, followed by 3 sets of 3 x 30-sec maximal sprints with 4 mins between each sprint *(1-min passive rest followed by 3-mins cycling at 100 W)* and 10-mins recovery *at* 60% of VO_{2max} between each set, and a 10-min cool down at 60% of VO_{2max}. Sprints were initiated from a rolling start. CON performed a time-matched session at a PO equivalent to 60% of VO_{2max}. Both groups were given continuous feedback during the transition period in order to match the training load reduction of both groups. Average weekly training load was reduced by 64% [5%] and 65% [10%] in SPR and CON respectively, with no significant difference in training load between groups.

Following the transition period, the athletes returned to their own self-selected training strategy for the first 6 weeks of the subsequent preparatory period. During this time, participants increased training load, and no differences in average weekly training load, training time or intensity distribution were observed between groups. Neither group performed SIT during the preparatory phase. No difference in total training load over the 13-week period was observed between groups. A final performance test was completed 6 weeks into the preparatory period

(PREP). Specific data regarding training characteristics during the three training periods can be found in Supplementary Table 2.

Figure 1

Methodology

Training Load

All training sessions, including an initial 4-week 'lead-in' period, were continuously monitored using the athletes personal HR monitors which were set to automatically sync each session to TrainingPeaks.com. Each session was classified as LIT, moderate intensity (MIT), HIT or SIT based on the session's intention as described in the athletes training log and confirmed with the resulting HR profile. Training load was quantified using the iTrimp method as described by Manzi el al.[23]

Testing Procedures

Participants were instructed to avoid consuming caffeine/stimulants 24 hrs prior to testing. Participants were also instructed to register food intake for 24 hrs prior to the COMP exercise test, and reminded to duplicate this intake at PREP. All testing was performed at the same time of day (±1 hr), in a controlled environmental condition (16–21°C and 20–35% humidity) with a fan to ensure air circulation around the rider. Verbal encouragement was given throughout all tests to encourage maximal effort. All exercise tests and sprint training sessions were supervised and performed on the Lode Excalibur Sport Cycle ergometer (Lode BV, Netherlands), using the same individual settings for both exercise tests. Figure 2 illustrates the exercise test protocol.

Figure 2

Blood lactate profile

Directly following a 10-min warm up, a strength test was conducted (data not shown here) followed by 10 mins of active recovery on the bike. After which a blood lactate profile was initiated at 175 W for 5 mins with 50 W increments every 5 mins thereafter. At a blood lactate concentration ($[BLa^-]$) of 3 $mmol \cdot L^{-1}$, the increments were 25 W until a $[BLa^-]$ of 4 $mmol \cdot L^{-1}$ or higher was obtained. Blood was sampled from the fingertip at the end of each 5-min increment and analyzed for whole blood $[BLa^-]$ using the Biosen C-Line Sport lactate measurement system (EKF Industrial Electronics, Magdeburg, Germany).

VO_{2max} test

Following the lactate profile test, the athletes cycled at 100 W for 10 minutes, with a 6-sec all-out sprint in the middle at minute 5. The sprint was initiated from stationary seated position, and cyclists were encouraged to reach peak PO. Thereafter, they performed an incremental test to exhaustion to determine VO_{2max}, starting at 200 or 250 W (depending on previous results) and PO increased by 25 W every minute until RPM dropped below 60 rpm, or the participant reached volitional exhaustion. VO_2 was measured using a computerized metabolic analyzer with a mixing chamber (Oxycon Pro, Erich Jaeger, Hoechberg Germany). The criteria to evaluate if VO_{2max} was achieved were; reaching 95% of known maximal HR, respiratory exchange ratio (RER) at or above 1.10, a plateau in VO_2 was obtained, $[BLa^-]$ 8.0 $mmol \cdot L^{-1}$ and visual exhaustion. VO_{2max} was calculated as the highest average of a 1-min moving average using 5-sec VO_2 measurements. W_{max} was calculated as the mean power output during the last minute of the incremental test.

60-min continuous cycling with 4 x 30-s maximal sprints

Following 10 min passive rest the participants proceeded with 60-min continuous cycling at a PO equivalent to 60% of VO_{2max}, which was calculated from the blood lactate profile and VO_{2max} using interpolation. VO_2 and RER were recorded from minute 5-10 and 30-35. Four 30-sec maximal sprints separated by 4-mins active rest (100W) were included between minute 36 to 50. Each sprint was started from a flying start at 80 rpm and a braking resistance of 0.8 $Nm \cdot kg^{-1}$ was applied to the flywheel throughout the 30-sec sprint. The participant was instructed to stay seated throughout the test, and strong verbal encouragement was given. Mean power output (MPO_{30sec}) was determined as the average of the 30-sec mean power outputs sustained throughout all 4 sprints.

20-min all-out test

Immediately following the 60-min protocol a 20-min self-paced all-out test began. Participants were blinded to average power during the test and were instructed to cycle at the highest average power output (PO_{20min}) possible. The participant self-selected their starting PO, which was replicated at PREP to ensure the same pacing conditions. VO_2 was measured from minute 4-5, 9-10 and 15-20. Mean performance-VO_2 was determined as the average of all recorded VO_2-measurements.

Gross Efficiency

Gross efficiency (GE), defined as the ratio between mechanical PO and metabolic input,[24] was calculated as described by Noordhof et al.[25] from the blood lactate profile test in the non-fatigued state (GE_{rest}) by interpolating the PO equivalent to 60% of VO_{2max} based on the 60-min continuous cycling test. Equivalently, the GE in the semi-fatigued state ($GE_{fatigue}$) was calculated using the mean of the steady-state period before sprinting (from min 5-10 and 30-35) in the 60-min continuous cycling test.

Statistical Analysis

All data are presented as mean [SD]. Shapiro-Wilk tests were used to confirm normal distribution and homogeneity of variance in all dependent variables. For the main analyses, a two-way mixed design ANOVA was used. The COMP and PREP timepoints were used as the within group factor. Strengths of associations were evaluated using partial eta squared (η). Contrast analysis was done using t-tests and the magnitude of differences between groups was assessed using Cohens d and adjusted with the correction factor for small sample sizes ($n<50$).[26] Effect sizes (ES) were interpreted as <0.2 (trivial), 0.2 to 0.6 (small), 0.6 to 1.2 (moderate), 1.2 to 2.0 (large) and >2.0 (very large).[27] A p-value < 0.05 was considered significant.

Results

20-min All-Out Performance

The main effect of time led to increased PO_{20min} ($p=0.05$, $\eta=0.363$) in absolute values but not relative to body mass ($p=0.136$, $\eta=0.229$). There was an interaction effect with SPR showing a greater improvement in average PO_{20min} from COMP to PREP (7.3 [7.2]%) than CON (-1.4% [4.6]%) both when expressed in absolute values (W; $p=0.047$, $\eta=0.371$) and relative to body mass ($W \cdot kg^{-1}$; $p=0.048$, $\eta=0.367$) (Table 2, Figure 3A). The mean change between the two groups had a moderate to large ES ($W \cdot kg^{-1}$; ES=1.1, W; ES=1.2). The performance improvement observed in SPR coincided with a 7.0 [3.6]% increase in average VO_2 throughout the 20-min all-out trial (with similar changes in $\%VO_{2max}$; Table 2), which was larger than the 0.7 [6.0]% increase in CON ($mL \cdot min^{-1}$; $p=0.042$)(Figure 3B). No changes were observed in average RPM throughout the 20-min trial ($p=0.685$) and there was a tendency for changed [BLa^-] 1-min after cessation ($p=0.055$).

Figure 3

Sprint Performance

There was no main effect of group ($p=0.699$, η=0.0.17) or time ($p=0.203$, $\eta=0.173$) in MPO_{30sec}. However, there was a tendency for a larger MPO_{30sec} improvement in SPR than CON from COMP to PREP, showing a moderate ES ($p=0.061$, $\eta=0.337$) (Table 2, Figure 4**)**. Specifically, SPR had a moderate improvement of 1.2 [4.8]% in MPO_{30sec} ($W \cdot kg^{-1}$) from COMP to PREP, while CON had a corresponding decline of 4.7 [4.5]%. SPR included one outlier with a large improvement in MPO_{30sec} while the others had a slight decline. Both groups improved peak PO during a 6-sec all sprint (PPO_{6sec}) (W; $p=0.016$, $W \cdot kg^{-1}$; $p=0.034$), but there was no difference between groups (W; $p=0.619$, $W \cdot kg^{-1}$; $p=0.654$).

Figure 4

VO_{2max}, GE, W_{max}, and Power Output at [La^-] of 4 $mmol \cdot L^{-1}$

There were no within- or between-group changes in VO_{2max}, GE_{rest}, $GE_{fatigue}$, W_{max} or PO at 4 $mmol \cdot L^{-1}$ [BLa^-] from COMP and PREP in either group (Table 2, **Figure 5A-C**; all $p>0.050$).

Figure 5

Table 2

Discussion

The main findings of the current study were that the inclusion of 30-sec maximal sprints in a weekly LIT session during a 3-week transition period improved 20-min all-out cycling performance 6 weeks into the subsequent preparatory period, which was not observed in CON. This improvement coincided with a larger increase in average performance-VO_2 throughout the 20-min all-out trial in SPR than CON. SPR tended to improve repeated sprint ability more than

CON. VO_{2max}, GE, W_{max} and PO at 4 mmol·L^{-1} [BLa^-] was maintained in both groups from COMP to PREP.

Six weeks after a 3-week transition period, during which SPR included 3 x 3 30-sec maximal sprints in a weekly LIT session and CON focused only on LIT, SPR demonstrated a 7% improvement to MPO_{20min}. This was larger than the decline observed by CON. These findings are consistent with previous research which showed enhanced endurance performance 16 weeks into the preparatory period of cyclists with the inclusion of a HIT stimulus during an 8-week transition period, while a LIT group was unable to improve their performance during the same time period.[8] The current study extends these findings to sprint training, which is regarded as an exercise which causes less strain than HIT,[10] and includes participants of a high training status. While it is common to see improvement in performance-determining variables during the preparatory period of cyclists,[1,3,6] the current study includes participants of a high training status whom are less likely to achieve sizeable improvements to endurance performance over such a short time period. Thus, a 7% improvement in PO_{20min} is substantial considering that there were no differences between the two groups at the end of the preceding competition season and no differences in training characteristics between the groups during the preparatory period. Improvements in PO_{20min} could be suggestive of improved race performance since cyclists perform near maximal aerobic capacity for durations of 15-20 minutes during time trials, breakaways and race finishes.[18] This is especially significant since the 20-min all-out test in the current study was conducted after prolonged exercise which is very competition relevant.

The PO_{20min} improvements observed in SPR were coincided by a 7% increase in mean VO_2 throughout the 20-min trial at PREP, an adaptation that was not apparent in CON. This increased "performance-VO_2" suggests that the performance improvement was not due to changes in VO_{2max}, but a higher fraction of VO_{2max} utilized during the test. This is likely linked to peripheral adaptions, as multiple studies have reported rapid changes to skeletal muscles following short-term sprint training interventions in trained individuals.[20,28-30] For example, Burgomaster et al.[29] demonstrated that following just 6 sprint training sessions over 2-weeks there was a significant increase to muscle oxidative capacity, and Iaia et al.[12] found that with the inclusion of sprint training, endurance trained runners were able to maintain their muscle oxidative capacity for four weeks despite a two thirds reduction in the total amount of training. It could be suggested that the performance improvements observed in SPR may be associated with the maintenance of valuable peripheral adaptations (i.e. muscle oxidative capacity) through the 3-week transition period, thus allowing them to progress the development of these adaptations in the subsequent 6 weeks of the preparatory period. Whereas CON likely would have required the preparatory period to recover lost adaptions. However, the current study found no change in PO at 4 mmol·L^{-1} [BLa^-] and in the absence of muscle biopsies we can do no more than speculate on mechanisms involved.

We found no changes in VO_{2max}, GE or W_{max} from COMP to PREP in the present study, which differ from the expected aerobic adaptations traditionally linked to improvements in endurance performance.[31] Additionally, neither group achieved an improvement in PO at 4 mmol·L^{-1} [BLa^-] from COMP to PREP, which is different from participants who showed rapid submaximal improvements following sprint training interventions,[17,29] and since PO at 4 mmol·L^{-1} [BLa^-] has previously been reported to increase during the preparatory period.[6] However, it is possible that the lack of statistical significance in the current study may be due to the short intervention period, the limited sample size and small potential for fluctuation in this homogenous group of elite cyclists with similar performance status.[32]

In the current study we only demonstrated a trend for improved MPO_{30sec} in SPR 6 weeks into the preparatory period. Although this change was not statistically different compared to CON, there was a moderate ES related to the inclusion of sprint training sessions in SPR. Following the three-week transition period, both groups trained with similar loads and intensity distribution, which might have reduced possible differences between groups in repeated sprint performance. One likely explanation for this is that anaerobic adaptions both occur and disappear relatively rapid. It has previously been suggested that PO_{30sec} improvements associated with sprint training could be related to the repeated high-power acceleration phase at the initiation of each sprint, which requires significant neuromuscular stimulation.[33] While it was not directly measured in our study, it is possible to theorize that the inclusion of sprints could have a protective effect on neuromuscular or anaerobic adaptions gained during the competition period.

Practical Applications

These findings hold important practical relevance on how coaches and athletes plan and execute their training during the transition period. Although competitive athletes should get sufficient time off during this period in order to promote physical and mental recovery, the results of the current study indicate that the inclusion of just one weekly sprint session could result in a valuable performance advantage in the subsequent preparatory period over those who focus solely on LIT during the same time period. While the applicability of adding sprints during the transition period seems to yield positive effects of competition relevant performance measures, sprints could also be added in other parts of the training season of elite cyclists i.e., during a tapering or periods of reduced training.

The superior PO_{20min} improvements of SPR might be influenced by the testing protocol, with fatiguing repeated sprints performed directly before testing for endurance performance, in which the SPR group could have been more specifically trained to tolerate. However, in our view this enriches the practical application of these findings where a race could likely be decided by multiple sprints, forming a break away followed by an all-out effort to the finish. However, future studies may also separate the test protocol, with sprint trials and the 20-min all-out test conducted on different days, especially when working with less trained populations.

It remains a challenge to attract a large group of high-level athletes as participants, and the current study is limited by the low sample size. Thus, it is possible that some findings were not discovered by the relatively low statistical power and the conservative approach of our analyses. Future research should be done with larger sample sizes, and athletes from different sports in order to gain a better understanding of the response to low volume training strategies during the transition period.

Conclusions

This study demonstrates that the inclusion of sprints in one weekly LIT-session during the 3-week transition period was sufficient to induce an endurance performance advantage, which is likely explained by a higher fractional utilization of VO_{2max}, 6 weeks into the preparatory period compared to those focusing solely on LIT during the transition period. In addition, both groups maintained key endurance performance-determining variables from the competitive period through to the preparatory period.

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Figure Captions

Figure 1 – Overview of the experimental design and training characteristics for both groups during each training period. LIT, low intensity training. MIT, moderate intensity training. HIT, high intensity training. SIT, sprint training. SPR, sprint training group. CON, control group doing only low intensity training. COMP, exercise test directly following the end of the competitive period. PREP, exercise test 6 weeks into the preparatory period. White arrow denotes an exercise test was completed; but data from this exercise test is only presented in a supplementary table. * significant difference in training intensity distribution between groups.

Figure 2 – Exercise test protocol. VO_{2max}, maximal oxygen uptake.

Figure 3 – (A) Mean power output and (B) mean oxygen uptake (VO_2) during a 20-minute all-out test at the end of the competition period (COMP), and 6-weeks into the preparatory period (PREP) following a 3-week transition period either including sprints in a weekly low-intensity session (SPR) or a control group doing only low intensity training (CON). ES, effect size. (*) significant difference in change between groups from COMP to PREP, $p<0.05$.

Figure 4 – Mean power output during 4 repeated 30-second maximal sprints at the end of the competition period (COMP), and 6-weeks into the preparatory period (PREP) following a 3-week transition period either including sprints in a weekly low-intensity (LIT)-session (SPR) or a control group doing only low intensity training (CON). ES, effect size.

Figure 5 – Absolute change in (A) maximal oxygen uptake (VO_{2max}), (B) maximal aerobic power output (W_{max}) and (C) power output at 4 mmol·L^{-1} [BLa^-] directly following the competitive season (COMP) and 6 weeks into the preparatory period (PREP) following a 3-week transition period either including sprints in a weekly low-intensity (LIT)-session (SPR) or a control group doing only low intensity training (CON). Individual data points, and mean values (bars). ES, effect size.

Table 1. Participant characteristics at pre-test after the competition period.

	SPR	***CON***	***Total***	***Group difference***
	(n = 5)	*(n = 6)*	*(n = 11)*	
Age (y)	23.1 [3.1]	21.0 [4.3]	22.0 [3.8]	p=0.37
Body mass (kg)	73.7 [6.7]	72.4 [5.6]	73.0 [5.8]	p=0.72
Height (cm)	186 [9]	186 [7]	186 [7]	p=0.96
VO_{2max} (mL·kg^{-1}·min^{-1})	74.5 [5.4]	69.3 [3.7]	71.7 [5.1]	p=0.10
W_{max} (W·kg^{-1})	6.2 [0.3]	5.9 [0.4]	6.0 [0.3]	p=0.29

Mean [SD]. VO_{2max}, maximal oxygen uptake. W_{max}, maximal aerobic power output. SPR, sprint interval group. CON, low intensity control group.

Table 2. Changes in physiological and performance variables from the end of the competitive period (COMP) to 6 weeks into the preparatory period (PREP), following a 3-week transition period with either a weekly sprint session (SPR) or a control group doing only low intensity training (CON).

	SPR (n=5)		CON (n=6)	
	COMP	PREP	COMP	PREP
Body mass (kg)	73.7 [6.7]	73.6 [6.4]	72.4 [5.6]	73.3 [4.4]
20-min all-out				
PO_{20min} (W)	295 [60]	316 [57]*	292 [44]	291 [45]*
%VO_{2max} (%)	77.5 [6.4]	84.7 [6.3]*	81.4 [4.8]	79.8 [7.1]*
VO_{2max}				
VO_{2max} (mL·min^{-1})	5469[384]	5373 [664]	5023 [554]	5176 [711]
VO_{2max} (mL·min^{-1}·kg^{-1})	74.5 [5.4]	72.5 [6.4]	69.3 [3.7]	70.8 [9.7]
W_{max} (W)	453 [35]	456 [58]	429 [50]	436 [50]
W_{max} (W·kg^{-1})	6.2 [0.3]	6.2 [0.5]	5.9 [0.4]	5.9 [0.5]
GE				
GE_{rest} (%)	20.0 [1.3]	19.7 [0.9]	19.9 [0.5]	20.7 [1.4]
$GE_{fatigue}$ (%)	20.4 [1.9]	19.7 [1.5]	20.1 [0.3]	19.7 [0.8]
4 mmol·L^{-1} [BLa^-]				
PO (W)	338 [62]	339 [65]	307 [45]	307 [43]
PO (W·kg^{-1})	4.6 [0.6]	4.6 [0.7]	4.2 [0.4]	4.1 [0.5]

30-sec Sprint				
MPO_{30sec} (W)	665 [58]	679 [88]	684 [83]	659 [72]

Values are mean [SD]. COMP, exercise test at the end of the competition season. PREP, exercise test 6 weeks into the preparatory period. PO_{20min}, mean power output during 20-minute all-out test. $\%VO_{2max}$, fractional utilization of maximal oxygen uptake. VO_{2max}, maximal oxygen uptake. W_{max}, maximum power output, measured as average power output during final minute of VO_{2max} test. GE, gross efficiency. GE_{rest} gross efficiency during the lactate profile at 60% of VO_{2max}. $GE_{fatigue}$ gross efficiency during the 60-min continuous riding at steady state in a semi-fatigued state. 4 $mmol \cdot L^{-1}$ [BLa^-], power output (PO) at 4 $mmol \cdot L^{-1}$ blood lactate. GE, gross efficiency. MPO_{30sec}, mean power output 30-sec sprints, 4 repeated 30-sec all-out sprints. (*) significant between groups change from COMP ($p < 0.05$).

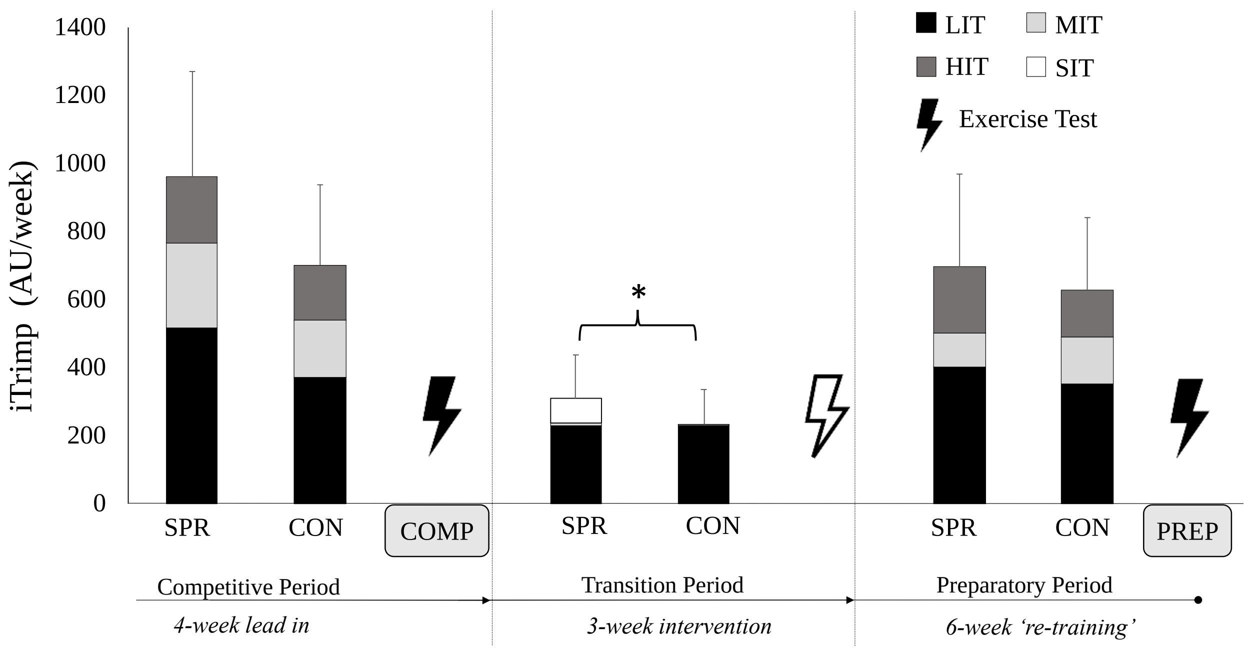

Figure 1: Overviewoftheexperimentaldesignandtrainingcharacteristicsforbothgroupsduringeachtrainingperiod.COMPindicatesexercisetest directly following the end of the competitive period; CON, control group doing only low-intensity training; HIT, high-intensity training; LIT, low- intensity training; MIT, moderate-intensity training; PREP, exercise test 6 weeks into the preparatory period; SPR, sprint training group; SIT, sprint training. White arrow denotes an exercise test was completed, but data from this exercise test are only presented in Supplementary Tables S1 and S2 (available online). *Significant difference in training intensity distribution between groups.

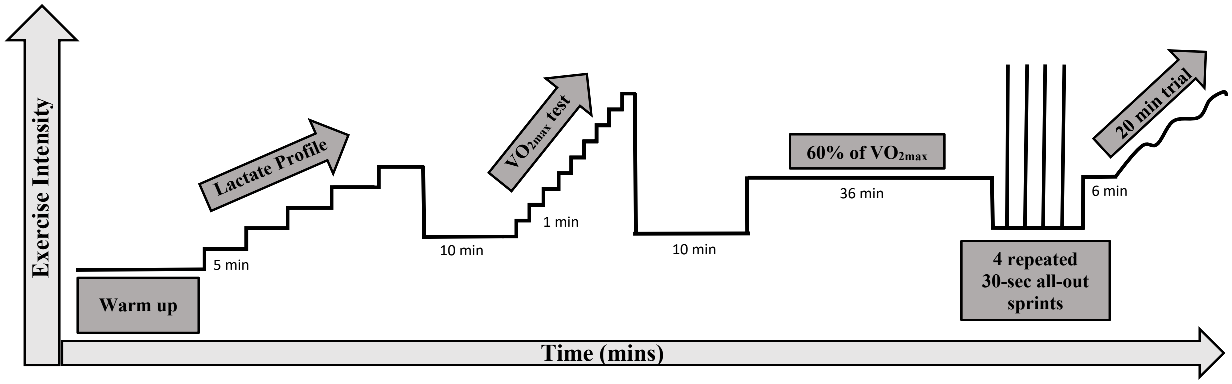

Figure 2. Exercise test protocol. VO_{2max}, maximal oxygen uptake.

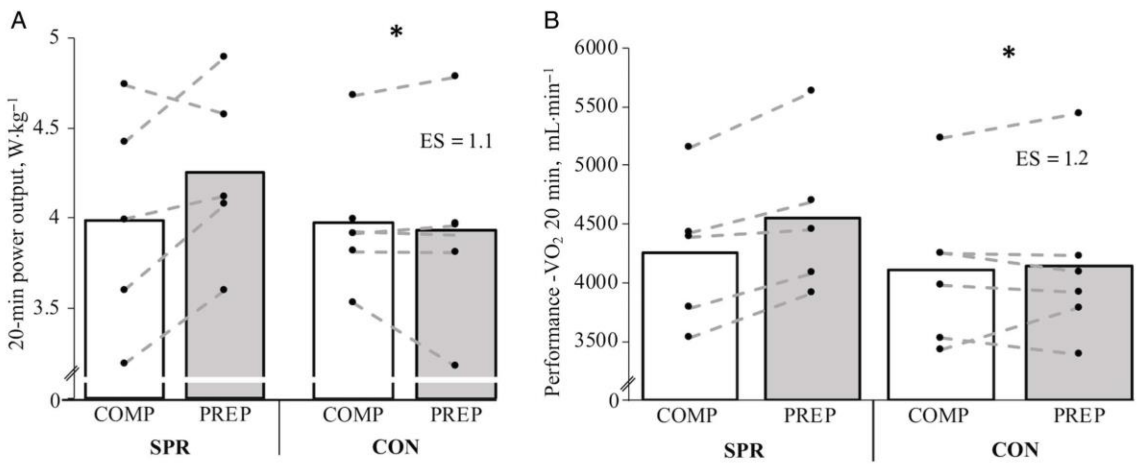

Figure 3. (A) Mean power output and (B) mean oxygen uptake (VO_2) during a 20-minute all-out test at the end of the competition period (COMP), and 6-weeks into the preparatory period (PREP) following a 3-week transition period with either a weekly sprint session (SPR) or a control group doing only low intensity training (CON) (*) significant difference in change between groups from COMP to PREP, $p<0.05$.

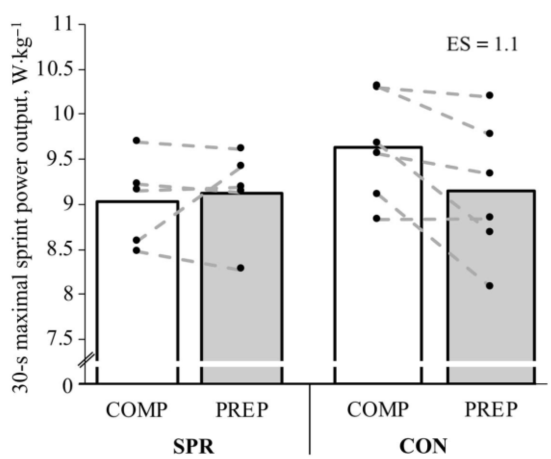

Figure 4 — Mean power output during 4 repeated 30-second maximal sprints at COMP and PREP following a 3-week transition period either including sprints in a weekly LIT session (SPR) or CON. COMP indicates exercise test at the end of

the competitive period; CON, control group doing only low-intensity training; ES, effect size; LIT, low-intensity session; PREP, exercise test 6 weeks into the preparatory period; SPR, sprint training group.

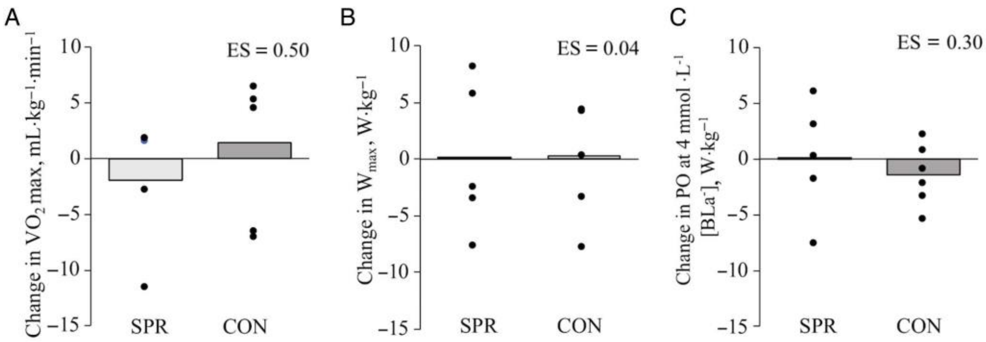

Figure 5 — Absolute change in (A) maximal oxygen uptake (VO_2max), (B) maximal aerobic power output (W_{max}), and (C) power output at 4 mmol·L^{-1} [BLa^{-}] directly following the COMP and PREP following a 3-week transition period either including sprints in a weekly LIT session (SPR) or CON. Individual data points and mean values (bars). CON indicates control group doing only low-intensity training; COMP, competitive season; ES, effect size; LIT, low-intensity training; PO, power output; PREP, exercise test 6 weeks into the preparatory period; SPR, sprint training group.

Supplementary tables

Supplementary Table 1. Physiological and performance variables following a 3-week transition period with either a weekly sprint session (SPR) or a control group who only performed low intensity training (CON)

	SPR	**CON**
	n=5	n=6
Body mass (kg)	74.2 [7.5]	73.1 [5.6]
20-min all-out		
PO_{20min} (W)	295 [44]	287 [3.9]
PO_{20min} (W·kg^{-1})	4.0 [0.4]	3.9 [0.4]
%VO_{2max} (%)	79.5 [6.5]	80.5 [4.3]
VO_{2max}		
VO_{2max} (mL·min^{-1})	5333 [453]	5111 [642]
VO_{2max} (mL·min^{-1}·kg^{-1})	72.1 [4.3]	69.8 [5.6]
W_{max} (W)	448 [41]	439 [43]
W_{max} (W·kg^{-1})	6.0 [0.3]	6.0 [0.4]
4 mmol·L^{-1} blood lactate		
PO (W)	319 [57]	299 [51]
PO (W·kg^{-1})	4.2 [0.5]	4.0 [0.4]
30-sec Sprint		
MPO_{30sec} (W)	683 [71]	665 [78]
MPO_{30sec} (W·kg^{-1})	9.2 [0.5]	9.1 [0.6]

Values are mean [SD]. SPR, sprint interval group. CON, low intensity group. PO_{20min}, mean power output during 20-minute all-out test. %VO_{2max}, fractional utalization of maximal oxygen uptake. VO_{2max}, maximal oxygen uptake. W_{max}, maximum power output, measured as average power output during final minute of VO_{2max} test. PO at 4 mmol, power output at 4 mmol L^{-1} [BLa-]. GE, gross efficiency. MPO_{30sec}, mean power output 30-sec sprints, 4 repeated 30-sec all-out sprints.

Supplementary Table 2. Training characteristics for competitive cyclists during the last 4 weeks of the competitive period, 3-weeks of transition with either a weekly sprint session (SPR) or a control group who only performed low intensity training (CON), and 6 weeks into the subsequent preparatory period.

	SPR (n=5)			**CON** (n=6)		
	Competition	Transition	Preparatory	Competition	Transition	Preparatory
Total Training (Weekly)						
iTrimp AU	847 [291]	307 [129]	679 [295]	661 [224]	236 [102]	611 [227]
Sessions	6.9 [0.3]	5.3 [1.7]	7.3 [0.7]	8.2 [4.7]	4.3 [1.4]	7.2 [1.4]
Hours	12.4 [3.9]	6.9 ± 2.0	8.9 [1.5]	13.7 [7.8]	6.3 [3.0]	9.0 [4.3]
Training Mode (%)						
Cycle	89 [7]	73 [11]	72 [13]	87 [14]	86 [15]	70 [16]
Strength	5 [7]	12 [12]	14 [10]	9 [14]	6 [10]	20 [10]
Other	5 [8]	15 [11]	14 [6]	4 [5]	8 [11]	11 [12]
Intensity Distribution (%)						
LIT	54 [14]	74 [4]	58 [10]	53 [16]	97 [4]	56 [11]
MIT	26 [10]	3 [24]	14 [7.0]	24 [10]	1 [3]	22 [6]
HIT/SIT*	20 [8]	23 [7]*	28 [6.6]	23 [13]	1 [2]	22 [8]

Data is represented as mean [SD]. Percentages represented as percentage of total session quantity. Individualized training impulse (iTrimp). Competition; last 4-weeks of the competition season. Transition, 3-week intervention period during which all sessions were done at low intensity for a control group (CON) or with the inclusion of 1-weekly SIT session (SPR). Preparatory, 6 weeks into the preparatory period. Arbitrary unit (AU); Low intensity training (LIT); Moderate intensity training (MIT); High intensity training (HIT); Sprint training (SIT). * sessions completed as sprint intervals.