International Journal of Sports Physiology and Performance, 2021, 16, 1502-1509
https://doi.org/10.1123/ijspp.2020-0594

Human Kinetics
ORIGINAL INVESTIGATION

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

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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 (PREP) 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·min^{-1}) reduced their training load by 64% and performed only LIT sessions (CON, n = 6) or included 3 sets of 3 × 30-second maximal sprints in a weekly LIT session (SPR, n = 5) during a 3-week transition period. There was no difference in the reduction in training load during the transition period between groups. Physiological and performance measures were compared between the end of the competitive period and 6 weeks into the PREP. ***Results:*** SPR demonstrated a 7.3% (7.2%) improvement in mean power output during a 20-minute all-out test at PREP, which was greater than CON (−1.3% [4.6%]) (P = .048). SPR had a corresponding 7.0% (3.6%) improvement in average VO_2 during the 20-minute all-out test, which was larger than the 0.7% (6.0%) change in CON (P = .042). No change in VO_2max, gross efficiency, or power output at blood lactate concentration of 4 mmol·L^{-1} from competitive period to PREP occurred in either group. ***Conclusion:*** Including sprints in a weekly LIT session during the transition period of elite cyclists provided a performance advantage 6 weeks into the subsequent PREP, which coincided with a higher performance VO_2.

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

The annual training season of a competitive cyclist is often broken into 3 periods: a competitive period, a transition period, and a preparatory period (PREP).[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 to 5 weeks of rest to promote recovery during the transition period. During this period, training volumes are decreased by 60% to 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 PREP 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 PREP. In contrast, members of a control group that only trained LIT experienced a physiological decline during the transition period and were unable to improve their endurance performance in the subsequent PREP. In addition, 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-second sprints have repeatedly been shown to improve anaerobic power and aerobic endurance performance in well-trained endurance athletes,[11–16] offering a high-intensity stimulus in a short amount of time. In addition, 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-second 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

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power for climbing, breakaways, race starts, and finishes.[2,18] In fact, races are often won or lost with a sprint finish (Menaspà, 2015 #257). Many competitive cyclists already use sprints to complement their endurance training 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-minute all-out time trial.[8,16,19] In addition, sprint training has been shown 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 PREP 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 PREP 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 with 4 Norwegian Universities (Norwegian University of Science and Technology in Trondheim, Inland University College in Lillehammer, Western Norway University of Applied Science in Bergen, and University of Agder in Agder) 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.[20] Specific data from our sample are provided in Supplementary Table S1 (available online).

Participants

Twenty-one elite male cyclists volunteered for this study. A subset of 13 cyclists were monitored for an additional 6 weeks into the subsequent PREP 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,[21] 7 participants were regarded as level 5 athletes ($VO_2max > 71$ mL·kg^{-1}·min^{-1}, maximal aerobic PO (W_{max}) > 5.5 W·kg^{-1}) and 4 participants were regarded as level 4 athletes ($VO_2max = 65–71$ mL·kg^{-1}·min^{-1}, $W_{max} = 4.9–6.4$ W·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 and approved by the Norwegian Social Science Data Service and the local committee at Lillehammer University College.

Design

The present study included 2 test periods (Figure 1). An initial performance test was completed 3 to 5 days after each cyclist's 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 (in iTrimp per week), training time (in hours per week), 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, whereas SPR included 3 supervised sessions (once per week) wherein sprints were included in LIT sessions. The 90-minute session included a 20-minute warm-up at 60% of VO_2max followed by 3 sets of 3 × 30 seconds maximal sprints with 4 minutes between each sprint (*1-min passive rest followed by 3-min cycling at 100 W*) and 10-minutes recovery at 60% of VO_2max between each set and a 10-minute cooldown 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 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 PREP. 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 PREP. Specific data regarding training characteristics during the 3 training periods can be found in Supplementary Table S2 (available online).

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 athlete's training log and confirmed with the resulting HR profile. Training load was quantified using the iTrimp method as described by Manzi et al.[22]

Table 1 Participant Characteristics at Pretest After the Competition Period

	Sprint interval group (n = 5)	Low-intensity control group (n = 6)	Total (N = 11)	Group difference
Age, y	23.1 (3.1)	21.0 (4.3)	22.0 (3.8)	$P = .37$
Body mass, kg	73.7 (6.7)	72.4 (5.6)	73.0 (5.8)	$P = .72$
Height, cm	186 (9)	186 (7)	186 (7)	$P = .96$
VO_2max, mL·kg^{-1}·min^{-1}	74.5 (5.4)	69.3 (3.7)	71.7 (5.1)	$P = .10$
W_{max}, W·kg^{-1}	6.2 (0.3)	5.9 (0.4)	6.0 (0.3)	$P = .29$

Abbreviations: VO_2max, maximal oxygen uptake; W_{max}, maximal aerobic power output. Note: Values are presented as mean (SD).

Testing Procedures. Participants were instructed to avoid consuming caffeine/stimulants 24 hours prior to testing. Participants were also instructed to register food intake for 24 hours 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 h) in a controlled environmental condition (16°C–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, The Netherlands) using the same individual settings for both exercise tests. Figure 2 illustrates the exercise test protocol.

Blood Lactate Profile. Directly following a 10-minute warm-up, a strength test was conducted (data not shown here) followed by 10 minutes of active recovery on the bike. After this, a blood lactate profile was initiated at 175 W for 5 minutes with 50 W increments every 5 minutes 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-minute 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-second 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

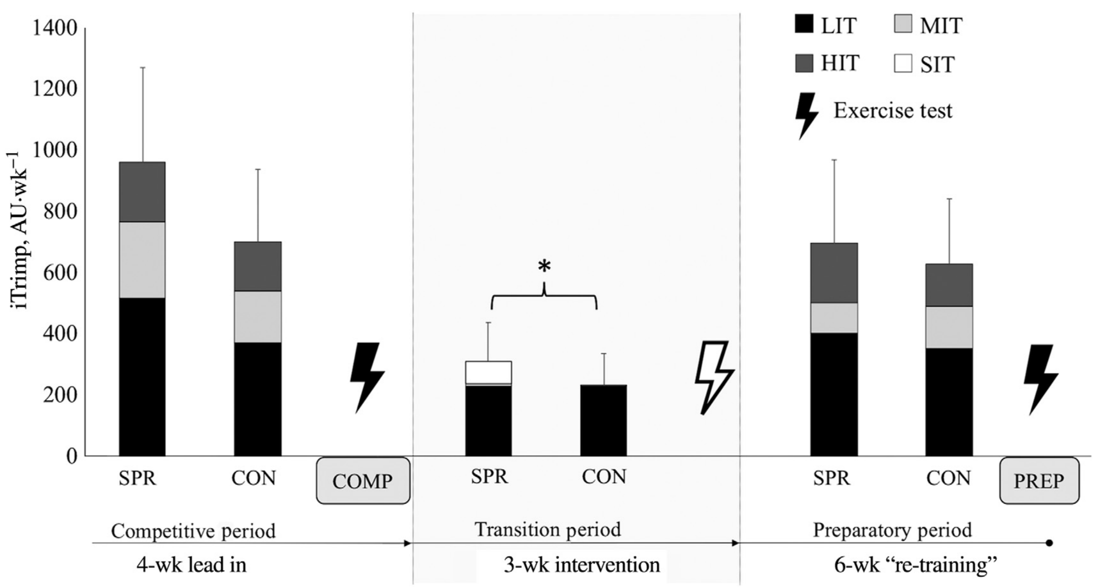

Figure 1 — Overview of the experimental design and training characteristics for both groups during each training period. COMP indicates exercise test directly following the end of the competitive period; CON, control group doing only low-intensity training; HIT, high-intensity training; LIT, low-intensity training; MIT, moderate-intensity training; PREP, exercise test 6 weeks into the preparatory period; SPR, sprint training group; SIT, sprint training. White arrow denotes that an exercise test was completed, but data from the test are only presented in Supplementary Tables S1 and S2 (available online). *Significant difference in training-intensity distribution between groups.

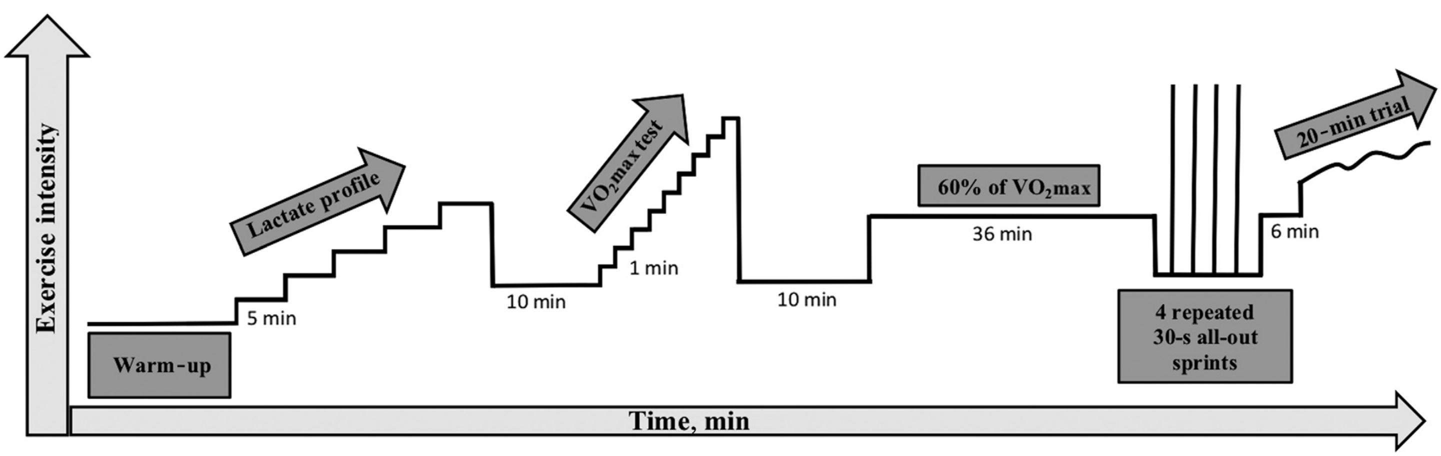

Figure 2 — Exercise test protocol. VO_2max indicates maximal oxygen uptake.

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 at or above 1.10, a plateau in VO_2 was obtained, [BLa^-] 8.0 mmol·L^{-1}, and visual exhaustion. VO_2max was calculated as the highest average of a 1-minute moving average using 5-second VO_2 measurements. W_{max} was calculated as the mean PO during the last minute of the incremental test.

60-Minute Continuous Cycling With 4 × 30-Second Maximal Sprints. Following 10-minutes passive rest, the participants proceeded with 60 minutes 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 respiratory exchange ratio were recorded from minute 5 to 10 and 30 to 35. Four 30-second maximal sprints separated by 4-minutes active rest (100W) were included between minute 36 and 50. Each sprint was started from a flying start at 80 rpm, and a braking resistance of 0.8 Nm·kg^{-1} was applied to the flywheel throughout the 30-second sprint. The participant was instructed to stay seated throughout the test, and strong verbal encouragement was given. Mean power output (MPO_{30s}) was determined as the average of the 30-second mean POs sustained throughout all 4 sprints.

20-Minute All-Out Test. Immediately following the 60-minute protocol, a 20-minute self-paced all-out test began. Participants were blinded to average power during the test and were instructed to cycle at the highest average PO (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 to 5, 9 to 10, and 15 to 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,[23] was calculated as described by Noordhof et al[24] from the blood lactate profile test in the nonfatigued state (GE_{rest}) by interpolating the PO equivalent to 60% of VO_2max based on the 60-minute 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 to 10 and 30 to 35) in the 60-minute 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 2-way mixed-design analysis of variance was used. The COMP and PREP time points were used as the within-group factor. Strengths of associations were evaluated using partial-eta squared (η_p^2). Contrast analysis was done using *t* tests, and the magnitude of differences between groups was assessed using Cohen *d* and adjusted with the correction factor for small sample sizes ($n < 50$).[25] 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).[26] A *P* value < .05 was considered significant.

Results

20-Minute All-Out Performance

The main effect of time led to increased PO_{20min} ($P = .05$, $\eta_p^2 = .363$) in absolute values but not relative to body mass ($P = .136$, $\eta_p^2 = .229$). 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; $P = .047$, $\eta_p^2 = .371$) and relative to body mass (W·kg^{-1}; $P = .048$, $\eta_p^2 = .367$) (Table 2, Figure 3A). The mean change between the 2 groups had a moderate to large ES (in Watts per kilogram; ES = 1.1, in Watts; ES = 1.2). The performance improvement observed in SPR coincided with a 7.0% (3.6%) increase in average VO_2 throughout the 20-minute all-out trial (with similar changes in %VO_2max; Table 2), which was larger than the 0.7% (6.0%) increase in CON (in milliliter per minute; $P = .042$) (Figure 3B). No changes were observed in average RPM throughout the 20-minute trial ($P = .685$), and there was a tendency for changed [BLa^-] 1 minute after cessation ($P = .055$).

Sprint Performance

There was no main effect of group ($P = .699$, $\eta_p^2 = .0.17$) or time ($P = .203$, $\eta_p^2 = .173$) in MPO_{30s}. However, there was a tendency for a larger MPO_{30s} improvement in SPR than CON from COMP to PREP, showing a moderate ES ($P = .061$, $\eta_p^2 = .337$) (Table 2, Figure 4). Specifically, SPR had a moderate improvement of 1.2% (4.8%) in MPO_{30s} (in Watts per kilograms) from COMP to PREP, whereas CON had a corresponding decline of 4.7% (4.5%). SPR included one outlier with a large improvement in MPO_{30s}, whereas the others had a slight decline. Both groups improved peak PO during a 6-second all-out sprint (PPO_{6s}) (in Watts; $P = .016$, in Watts per kilograms; $P = .034$), but there was no difference between groups (in Watts; $P = .619$, in Watts per kilograms; $P = .654$).

VO_2max, GE, W_{max}, and PO at [BLa^-] of 4 mmol·L^{-1}

There were no within- or between-groups changes in VO_2max, GE_{rest}, $GE_{fatigue}$, W_{max}, or PO at 4 mmol·L^{-1} [BLa^-] from COMP and PREP in either group (Table 2, Figure 5A–5C; all $P > .050$).

Discussion

The main findings of the current study were that the inclusion of 30-seconds maximal sprints in a weekly LIT session during a 3-week transition period improved 20-minute all-out cycling performance 6 weeks into the subsequent PREP, which was not observed in CON. This improvement coincided with a larger increase in average performance VO_2 throughout the 20-minute all-out trial in SPR than CON. The SPR tended to improve repeated sprint ability more than CON. The 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 × 3 30-second 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 PREP of cyclists with the inclusion of a HIT stimulus during an 8-week transition period, whereas members of a LIT group were 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 that causes less strain than HIT[10] and includes participants of a high training status. Although it is common to see improvement in performance-determining variables during the PREP of cyclists,[1,3,6] the current study includes

Table 2 Changes in Physiological and Performance Variables From the End of the COMP to PREP Following a 3-Week Transition Period Either Including Sprints in a Weekly Low-Intensity Session or a Control Group Doing Only Low-Intensity Training

	SPR (n = 5)		CON (n = 6)		
	COMP	PREP	COMP	PREP	Effect size
Body mass, kg	73.7 (6.7)	73.6 (6.4)	72.4 (5.6)	73.3 (4.4)	0.31
20-min all-out					
PO_{20min}, W	295 (60)	316 (57)*	292 (44)	291 (45)*	1.2
$\%VO_2max$, %	77.5 (6.4)	84.7 (6.3)*	81.3 (4.3)	79.8 (6.5)*	−1.2
VO_2max					
VO_2max, $mL \cdot min^{-1}$	5469 (384)	5373 (664)	5023 (554)	5176 (711)	0.50
VO_2max, $mL \cdot min^{-1} \cdot kg^{-1}$	74.5 (5.4)	72.5 (6.4)	69.3 (3.7)	70.8 (9.7)	0.45
W_{max}, W	453 (35)	456 (58)	429 (50)	436 (50)	0.13
W_{max}, $W \cdot kg^{-1}$	6.2 (0.3)	6.2 (0.5)	5.9 (0.4)	5.9 (0.5)	0.04
Gross efficiency					
GE_{rest}, %	20.0 (1.3)	19.7 (0.9)	19.9 (0.5)	20.7 (1.4)	0.52
$GE_{fatigue}$, %	20.4 (1.9)	19.7 (1.5)	20.1 (0.3)	19.7 (0.8)	0.69
4 $mmol \cdot L^{-1}$ [BLa^-]					
PO, W	338 (62)	339 (65)	307 (45)	307 (43)	−0.17
PO, $W \cdot kg^{-1}$	4.6 (0.6)	4.6 (0.7)	4.2 (0.4)	4.1 (0.5)	0.30
Sprints					
MPO_{30s}, W	665 (58)	679 (88)	684 (83)	659 (72)	1.02
PPO_{6s}, W	1371 (190)	1421 (205)	1340 (74)	1411 (91)	0.26
PPO_{6s}, $W \cdot kg^{-1}$	18.7 (2.7)	19.2 (2.7)	18.5 (0.66)	19.3 (1.2)	0.23

Abbreviations: [BLa^-], blood lactate; $\%VO_2max$, fractional utilization of VO_2max; COMP, exercise test at the end of the competition season; $GE_{fatigue}$, gross efficiency during the 60-minute continuous riding at steady state in a semifatigued state; GE_{rest}, gross efficiency during the lactate profile at 60% of VO_2max; MPO_{30s}, mean power output 30-second sprints, 4 repeated 30-second all-out sprints; PO, power output; PO_{20min}, mean PO during 20-minute all-out test; PPO_{6s}, peak PO during a 6-second sprint; PREP, exercise test 6 weeks into the preparatory period; VO_2max, maximal oxygen uptake; W_{max}, maximum aerobic power, measured as average power output during final minute of VO_2max test. Note: Values are mean (SD).
*Significant between-groups change from COMP ($P < .05$).

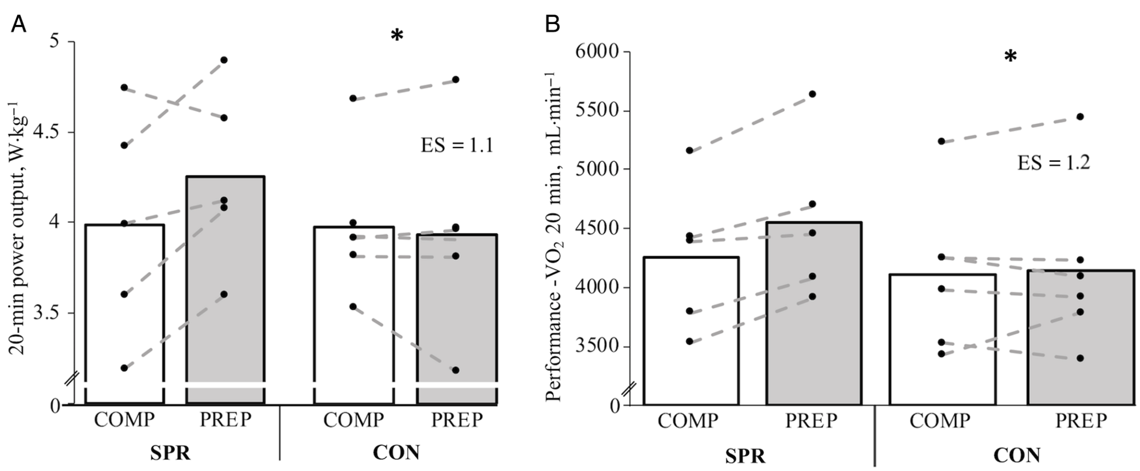

Figure 3 — (A) Mean power output and (B) mean oxygen uptake (VO_2) during a 20-minute all-out test at COMP and PREP following a 3-week transition period either including sprints in a weekly low-intensity session (SPR) or CON. COMP indicates exercise test at the end of the competitive period; CON, control group doing only low-intensity training; PREP, exercise test 6 weeks into the preparatory period; SPR, sprint training group; ES, effect size. *Significant difference in change between groups from COMP to PREP, $P < .05$.

participants of a high training status who 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 2 groups at the end of the preceding competition season and no differences in training characteristics between the groups during the PREP. Improvements in PO_{20min} could be suggestive of improved race performance since cyclists perform near maximal aerobic capacity for durations of 15 to 20 minutes during time trials, breakaways, and race finishes.[18] This is especially significant since the 20-minute 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-minute 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.[19,27–29] For example, Burgomaster et al[28] demonstrated that following just 6 sprint training sessions over 2 weeks, there was a significant increase in 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 4 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 (ie, muscle oxidative capacity) through the 3-week transition period, thus allowing cyclists to progress the development of these adaptations in the subsequent 6 weeks of the PREP, whereas CON likely would have required the PREP 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.

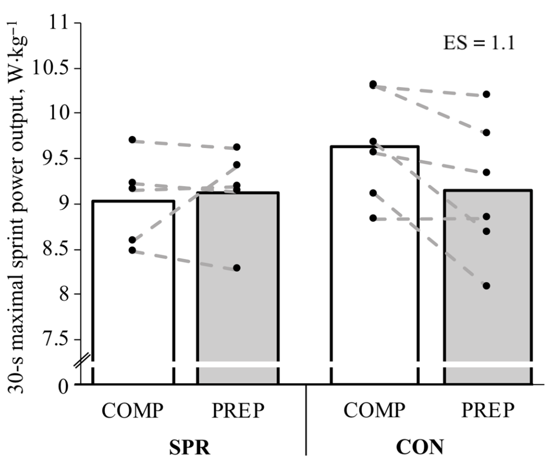

Figure 4 — Mean power output during 4 repeated 30-second maximal sprints at COMP and PREP following a 3-week transition period either including sprints in a weekly LIT session (SPR) or CON. COMP indicates exercise test at the end of the competitive period; CON, control group doing only low-intensity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

We found no changes in VO_2max, GE, or W_{max} from COMP to PREP in the present study, which differs from the expected aerobic adaptations traditionally linked to improvements in endurance performance.[30] In addition, 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[17,28] and since PO at 4 mmol·L^{-1} [BLa^-] has previously been reported to increase during the PREP.[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.[31]

In the current study, we only demonstrated a trend for improved MPO_{30s} in SPR 6 weeks into the PREP. Although this change was not statistically different compared with CON, there was a moderate ES related to the inclusion of sprint training sessions in SPR. Following the 3-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 rapidly. 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.[32]

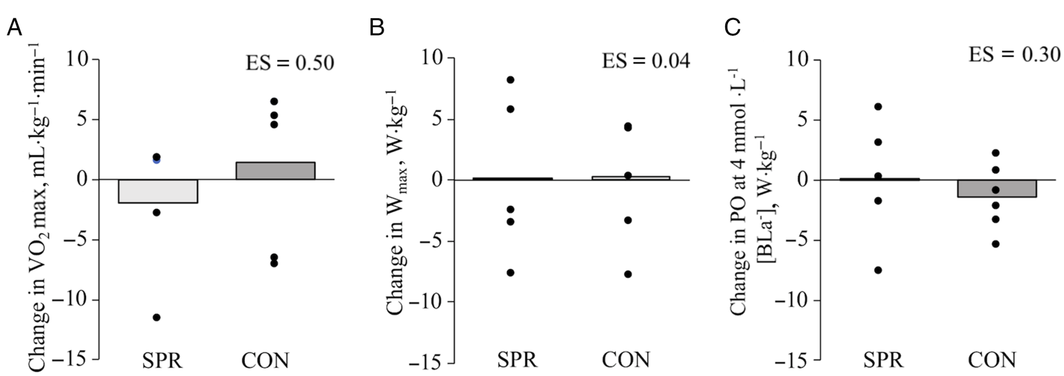

Figure 5 — Absolute change in (A) maximal oxygen uptake (VO_2max), (B) maximal aerobic power output (W_{max}), and (C) power output at 4 mmol·L^{-1} [BLa^-] directly following the COMP and PREP after a 3-week transition period either including sprints in a weekly LIT session (SPR) or CON. Individual 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.

Although 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 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 PREP over focusing solely on LIT during the same time period. Although 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, that is, during a tapering or periods of reduced training.

The testing protocol, which included fatiguing repeated sprints performed directly before testing endurance performance, may have influenced the superior PO_{20min} improvements of SPR, as they could have been more specifically trained to tolerate this type of stimulus. However, in our view, this enriches the practical application of these findings wherein 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-minute 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 to gain a better understanding of the response to low-volume training strategies during the transition period.

Conclusion

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 PREP compared with 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 PREP.

Acknowledgments

The authors would like to thank all of the athletes and coaches for their participation. The testing in Trondheim was provided by NeXt Move, Norwegian University of Science and Technology. NeXt Move is funded by the Faculty of Medicine at NTNU and Central Norway Regional Health Authority.

References

1. Mujika I, Halson S, Burke LM, Balague G, Farrow D. An integrated, multifactorial approach to periodization for optimal performance in individual and team sports. *Int J Sports Physiol Perform*. 2018;13(5):538–561. PubMed ID: 29848161 doi:10.1123/ijspp.2018-0093
2. Lucia A, Hoyos J, Chicharro JL. Physiology of professional road cycling. *Sports Med*. 2001;31(5):325–337. PubMed ID: 11347684 doi:10.2165/00007256-200131050-00004
3. Sassi A, Impellizzeri FM, Morelli A, Menaspa P, Rampinini E. Seasonal changes in aerobic fitness indices in elite cyclists. *Appl Physiol Nutr Metab*. 2008;33(4):735–742. PubMed ID: 18641717 doi:10.1139/H08-046
4. Lucia A, Hoyos J, Pardo J, Chicharro JL. Metabolic and neuromuscular adaptations to endurance training in professional cyclists: a longitudinal study. *Jpn J Physiol*. 2000;50(3):381–388. PubMed ID: 11016988
5. Maldonado-Martin S, Camara J, James DVB, Fernandez-Lopez JR, Artetxe-Gezuraga X. Effects of long-term training cessation in young top-level road cyclists. *J Sports Sci*. 2017;35(14):1396–1401. PubMed ID: 27476326
6. Paton CD, Hopkins WG. Seasonal changes in power of competitive cyclists: implications for monitoring performance. *J Sci Med Sport*. 2005;8(4):375–381. PubMed ID: 16602165 doi:10.1016/S1440-2440(05)80052-0
7. Mujika I, Chatard JC, Busso T, Geyssant A, Barale F, Lacoste L. Effects of training on performance in competitive swimming. *Can J Appl Physiol*. 1995;20(4):395–406. PubMed ID: 8563672 doi:10.1139/h95-031
8. Rønnestad BR, Askestad A, Hansen J. HIT maintains performance during the transition period and improves next season performance in well-trained cyclists. *Eur J Appl Physiol*. 2014;114(9):1831–1839. PubMed ID: 24878691 doi:10.1007/s00421-014-2919-5
9. Mallol M, Bentley DJ, Norton L, Norton K, Mejuto G, Yanci J. Comparison of reduced-volume high-intensity interval training and high-volume training on endurance performance in triathletes. *Int J Sports Physiol Perform*. 2019;14(2):239–245. PubMed ID: 30080432 doi:10.1123/ijspp.2018-0359
10. Valstad SA, von Heimburg E, Welde B, van den Tillaar R. Comparison of long and short high-intensity interval exercise bouts on running performance, physiological and perceptual responses. *Sports Med Int Open*. 2018;2(1):E20–E27. PubMed ID: 30539113 doi:10.1055/s-0043-124429
11. Bangsbo J. Performance in sports—with specific emphasis on the effect of intensified training. *Scand J Med Sci Sports*. 2015;25:88–99. PubMed ID: 26589122 doi:10.1111/sms.12605
12. Iaia FM, Hellsten Y, Nielsen JJ, Fernstrom M, Sahlin K, Bangsbo J. Four weeks of speed endurance training reduces energy expenditure during exercise and maintains muscle oxidative capacity despite a reduction in training volume. *J Appl Physiol*. 2009;106(1):73–80. PubMed ID: 18845781 doi:10.1152/japplphysiol.90676.2008
13. Creer AR, Ricard MD, Conlee RK, Hoyt GL, Parcell AC. Neural, metabolic, and performance adaptations to four weeks of high intensity sprint-interval training in trained cyclists. *Int J Sports Med*. 2004;25(2):92–98. doi:10.1055/s-2004-819945
14. Laursen PB, Shing CM, Peake JM, Coombes JS, Jenkins DG. Interval training program optimization in highly trained endurance cyclists. *Med Sci Sports Exerc*. 2002;34(11):1801–1807. PubMed ID: 12439086 doi:10.1097/00005768-200211000-00017
15. Gist N, Fedewa M, Dishman R, Cureton K. Sprint interval training effects on aerobic capacity: a systematic review and meta-analysis. *Sports Med*. 2014;44(2):269–279. PubMed ID: 24129784 doi:10.1007/s40279-013-0115-0
16. Rønnestad BR, Hansen J, Vegge G, Tønnessen E, Slettaløkken G. Short intervals induce superior training adaptations compared with

long intervals in cyclists – an effort-matched approach. *Scand J Med Sci Sports*. 2015;25(2):143–151. PubMed ID: 24382021 doi:10.1111/sms.12165

17. Gibala MJ, Little JP, van Essen M, et al. Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. *J Physiol*. 2006;575(3):901–911. doi:10.1113/jphysiol.2006.112094
18. Menaspà P, Quod M, Martin D, Peiffer J, Abbiss C. Physical demands of sprinting in professional road cycling. *J Strength Cond Res*. 2015;36(13):1058–1062. doi:10.1055/s-0035-1554697
19. Gunnarsson TP, Brandt N, Fiorenza M, Hostrup M, Pilegaard H, Bangsbo J. Inclusion of sprints in moderate intensity continuous training leads to muscle oxidative adaptations in trained individuals. *Physiol Rep*. 2019;7(4):e13976. PubMed ID: 30793541 doi:10.14814/phy2.13976
20. Almquist NW, Løvlien I, Byrkjedal PT, et al. Effects of including sprints in one weekly low-intensity training session during the transition period of elite cyclists. *Front Physiol*. 2020;11:1000.
21. De Pauw K, Roelands B, Cheung SS, de Geus B, Rietjens G, Meeusen R. Guidelines to classify subject groups in sport-science research. *Int J Sports Physiol Perform*. 2013;8(2):111–122. PubMed ID: 23428482 doi:10.1123/ijspp.8.2.111
22. Manzi V, Iellamo F, Impellizzeri F, D'Ottavio S, Castagna C. Relation between individualized training impulses and performance in distance runners. *Med Sci Sports Exerc*. 2009;41(11):2090–2096. PubMed ID: 19812506 doi:10.1249/MSS.0b013e3181a6a959
23. Peronnet F, Massicotte D. Table of nonprotein respiratory quotient: an update. *Can J Sport Sci*. 1991;16(1):23–29. PubMed ID: 1645211
24. Noordhof DA, Skiba PF, de Koning JJ. Determining anaerobic capacity in sporting activities. *Int J Sports Physiol Perform*. 2013;8(5):475–482. PubMed ID: 24026759 doi:10.1123/ijspp.8.5.475
25. Durlak JA. How to select, calculate, and interpret effect sizes. *J Pediatr Psychol*. 2009;34(9):917–928. PubMed ID: 19223279 doi:10.1093/jpepsy/jsp004
26. Hopkins GW, Marshall WS, Batterham MA, Hanin MJ. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41(1):3–13. PubMed ID: 19092709 doi:10.1249/MSS.0b013e31818cb278
27. MacDougall JD, Hicks AL, MacDonald JR, McKelvie RS, Green HJ, Smith KM. Muscle performance and enzymatic adaptations to sprint interval training. *J Appl Physiol*. 1998;84(6):2138–2142. doi:10.1152/jappl.1998.84.6.2138
28. Burgomaster KA, Hughes SC, Heigenhauser GJ, Bradwell SN, Gibala MJ. Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. *J Appl Physiol*. 2005;98(6):1985–1990. PubMed ID: 15705728 doi:10.1152/japplphysiol.01095.2004
29. MacInnis MJ, Gibala MJ. Physiological adaptations to interval training and the role of exercise intensity. *J Physiol*. 2017;595(9):2915–2930. PubMed ID: 27748956 doi:10.1113/JP273196
30. Joyner MJ, Coyle EF. Endurance exercise performance: the physiology of champions. *J Physiol*. 2008;586(1):35–44. PubMed ID: 17901124 doi:10.1113/jphysiol.2007.143834
31. Bassett RD, Howely ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Med Sci Sports Exerc*. 2000;32(1):70–84. PubMed ID: 10647532 doi:10.1097/00005768-200001000-00012
32. Taylor J, Macpherson T, Spears I, Weston M. The effects of repeated-sprint training on field-based fitness measures: a meta-analysis of controlled and non-controlled trials. *Sports Med*. 2015;45(6):881–891. PubMed ID: 25790793 doi:10.1007/s40279-015-0324-9