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# ACUTE PRIOR HEAVY STRENGTH EXERCISE BOUTS IMPROVE THE 20-KM CYCLING TIME TRIAL PERFORMANCE

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## ABSTRACT

Silva, RAS, Silva-Júnior, FL, Pinheiro, FA, Souza, PFM, Boullosa, DA, and Pires, FO. Acute prior heavy strength exercise bouts improve the 20-km cycling time trial performance. *J Strength Cond Res* 28(9): 2513–2520, 2014—This study verified if a prior 5 repetition maximum (5RM) strength exercise would improve the cycling performance during a 20-km cycling time trial (TT<sub>20km</sub>). After determination of the 5RM leg press exercise load, 11 trained cyclists performed a TT<sub>20km</sub> in a control condition and 10-minute after 4 sets of 5RM strength exercise bouts (potentiation condition). Oxygen uptake, blood lactate concentration, ratings of perceived exertion (RPE), and power output data were recorded during the TT<sub>20km</sub>. Cycling economy index was assessed before the TT<sub>20km</sub>, and pacing strategy was analyzed assuming a “J-shaped” power output distribution profile. Results were a 6.1% reduction ( $p \leq 0.05$ ) in the time to complete the TT<sub>20km</sub>, a greater cycling economy ( $p < 0.01$ ), and power output in the first 10% of the TT<sub>20km</sub> (i.e., trend;  $p = 0.06$ ) in the potentiation condition. However, no differences were observed in pacing strategy, physiological parameters, and RPE between the conditions. These results suggest that 5RM strength exercise bouts improve the performance in a subsequent TT<sub>20km</sub>.

**KEY WORDS** potentiation, pacing strategy, complex training

## INTRODUCTION

**D**uring cycling time trials, athletes are required to produce high values of power output to complete a given distance in the shortest possible time. For a practical point of view, coaches

and athletes are interested in chronic and acute interventions which may increase the athletes' capacity to produce higher power output, thus improving the cycling performance (14,17,18,22). Regarding acute interventions, different cycling warm-up strategies have been suggested to improve the performance during a subsequent short cycling time trial (18). For example, using controlled-pace or self-paced cycling exercises, studies found increases in the mean power output and time to complete a 4-km time trial after the warm-up strategy (3,18); they concluded that the improved performance was attributed to an earlier aerobic energy provision with a greater anaerobic contribution during the last part of the trial.

An alternative to the specific acute warm-up interventions with cycling exercises may be strength exercises. A body of evidence supports that prior heavy, maximum or near maximum, strength exercise bouts improve the performance of a subsequent exercise bout (9,23). Studies have shown that heavy-intensity exercise bouts such as strength exercises composed of a few repetitions maximum (RM) were able to potentiate the performance during subsequent running bouts (5,13). For example, Chatzopoulos et al. (5) found increases in the 30-m all-out running velocity after a 10RM back half squat, whereas Linder et al. (13) observed a 0.19-second improvement in the time to finish a 100-m sprint running after a 4RM back half squats. It is possible that the improved running performance after the RM strength exercises in these studies may be attributed to an increased velocity (i.e., power output) as it has been acknowledged that heavy conditioning activities may increase the power output in different subsequent tasks (26).

Regarding the cycling modality, no studies have evaluated if heavy-intensity strength exercise bouts would affect the cycling time trial performance. It has been acknowledged that cycling performance is related to the power output (16) and its distribution over the trial, a concept currently known as pacing strategy (24). For example, a fast start pacing (i.e., greater power output during the first 10% of the trial) was suggested to alter the cycling performance and the

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perceptive and physiological responses in a 20-km time trial (TT<sub>20km</sub>) (24). For this scenario, it would be interesting to verify if nonspecific warm-up strategies such as heavy-intensity strength exercise bouts may alter the mean power output and its distribution during a cycling time trial, thus improving the cycling performance. A potentiated cycling performance resulting from heavy-intensity strength exercise bouts would be attractive as cyclists are used to performing complex training programs which include concurrent strength and endurance exercises in the same training session.

Therefore, the aim of this study was to verify if prior heavy-intensity strength exercise bouts would alter the mean power output and improve the performance in a subsequent cycling time trial. The hypothesis was that 4 sets of 5 repetition maximum (5RM) strength exercise would increase the power output and reduce the time to complete a TT<sub>20km</sub>. Furthermore, as the effect of prior heavy-intensity strength exercise bouts on the cycling pacing strategy is unknown, we were also interested in verifying if the prior heavy-intensity strength exercise would alter the pacing.

## METHODS

### Experimental Approach to the Problem

To verify if prior heavy-intensity strength exercise bouts would improve the performance in a subsequent cycling time trial, a group of well-trained cyclists performed 2 TT<sub>20km</sub> in a repeated measure design comprised of a control session without prior strength exercises intervention (i.e., baseline condition) and an experimental session with prior execution of 5RM leg press exercise bouts. After familiarization with procedures and determination of the 5RM load, cyclists performed the control TT<sub>20km</sub> and the experimental TT<sub>20km</sub> in a counterbalanced design. The RM strength exercise comprised of 4 sets of 5RM leg press exercise. Cardiopulmonary and metabolic variables and ratings of perceived exertion (RPE) were measured before and throughout the exercises. All tests were performed at the same time of the day in a controlled laboratory environment (~20°C temperature and ~60% humidity), interspersed with a 72-hour interval. Cyclists were recommended to avoid intense training and consumption of alcoholic and stimulant beverages before the sessions. In addition, they were recommended to use habitual dietary intake for the 48 hours before the visits.

### Subjects

Eleven male cyclists (32 ± 6 years, age range from 27–43 years, 72.7 ± 11.9 kg, 172.2 ± 8.9 cm, and 10.3 ± 5.4% of body fat) who experienced in time trials and competing regularly when the study was conducted were volunteers for this study. Most of the cyclists were specialist in speed cycling trials with an average training background of 4 years (2–10 years). Their training schedule involved approximately 420 km of cycling performed at moderate-heavy aerobic intensity, within 5–7 sessions per week. All cyclists were nonsmokers, free from cardiopulmonary or neuromuscular

disorders and achieved a peak oxygen uptake ( $\dot{V}O_{2peak}$ ) of 56.7 ± 6.7 ml·kg<sup>-1</sup>·min<sup>-1</sup> and a peak power output ( $W_{peak}$ ) of 298.1 ± 26.6 W in the incremental preliminary test. All risks and benefits of the experimental procedures were discussed with participants before obtaining written informed consent. The study was approved by a local Ethics and Research Committee and conducted in accordance with the Helsinki Declaration (8).

### Procedures

**Incremental Cycling Test.** Measures of body mass, height, and 3 skinfolds (Lange Caliper; Creative Health Products, Ann Arbor, MI, USA) were obtained to determine the body density and body fat percentage of all participants (10). Thereafter, cyclists underwent an incremental cycling test to exhaustion (Excalibur; Lode, Holland, the Netherlands) to determine  $\dot{V}O_{2peak}$  and  $W_{peak}$ . The initial workload was set at 100 W with increments of 30 W every 3-minute performed until exhaustion. Exhaustion was defined as the incapacity of participants to maintain a pedal cadence ≥70 rpm, despite strong verbal encouragement. Oxygen uptake ( $\dot{V}O_2$ ) was continuously recorded with a computerized system (Metalyzer 3B; Biophysic, Cortex, Leipzig, Germany) after calibration according to the manufacturer's instructions. The calibration used ambient air and a known composition gas (20.9% O<sub>2</sub> and 5% CO<sub>2</sub>), whereas the turbine flow meter was calibrated using a 3-L syringe (Quinton Instruments; Bothell, WA, USA). Breath-by-breath  $\dot{V}O_2$  data were converted to 20-second averages, and the  $\dot{V}O_{2peak}$  was determined as the average of the 3 highest  $\dot{V}O_2$  values obtained in the test (25). The  $W_{peak}$  was determined as the highest power output attained at exhaustion during the incremental cycling test, and used thereafter to report the power output results obtained during the TT<sub>20km</sub> as %  $W_{peak}$ .

**Familiarization Session 11.** Squat and leg press exercises are commonly performed in complex concurrent training programs for cyclists. Although some studies have found increased performance after back half squats (5,13), it was suggested that potentiation effects also depend on the individual's training background (21). Thus, a leg press exercise comprised of 4 sets of 5RM was employed as cyclists of this study were used to performing leg press exercises with similar RM-number of sets during their complex training sessions.

After a standard warm-up using a 45° leg press apparatus (Riguetto; Powertech, Brazil) with loads of 50–70% of body mass, cyclists performed up to 5 attempts to get an initial estimation of the 5RM. Tape was fixed on the plate of the equipment to ensure the use of the same starting body position for each session. The knee and hip angles were set at 90° and 45°, respectively, and every knee and hip extension-flexion cycle was set to a cadence of 4-seconds. Rather than controlling the eccentric-concentric cycle duration, the 4-second extension-flexion cadence was used to standardize the strength exercise bouts duration. In addition, a 5RM

**TABLE 1.** Overall performance responses (mean ± SD) during the TT<sub>20km</sub> in both the control and potentiation condition.\*†

Variables	Control	Potentiation	% of control	<i>p</i>
Time (min)	28.1 ± 4.0	26.6 ± 3.9	-6.1	0.02
W <sub>mean</sub> (W)	247.4 ± 67.5	254.9 ± 65.2	+3.0	0.21
RPM <sub>mean</sub> (rpm)	95.6 ± 10.8	96.6 ± 14.0	-0.1	0.59

\*TT<sub>20km</sub> = 20-km time trial.  
 †W<sub>mean</sub> and W<sub>peak</sub> are the mean and peak power output throughout the trial, respectively;  
 RPM<sub>mean</sub> and RPM<sub>peak</sub> are the mean and peak pedal cadence throughout the trial, respectively.

strength exercise was used to represent the RM range normally used in studies, which reported potentiation effects after heavy-intensity strength exercises (5,13).

After the estimation of the 5RM strength exercise load, cyclists remained in a resting state for 15 minutes before familiarization with the laboratory TT<sub>20km</sub> as they were accustomed to TT<sub>20km</sub>s during trainings and competitions outside of the laboratory. During the TT<sub>20km</sub>, each participant connected his/her own bike to a cycle simulator (Spin-Trainer; TechnoGym, Italy) that was calibrated according to the manufacture’s recommendation. Cyclists were allowed to use their own bike to complete the TT<sub>20km</sub> as we expected that potentiation effects may be reduced if a bike with unusual settings was used. After a brief cycling warm-up, cyclists were advised to finish the TT<sub>20km</sub> in the fastest time possible with strong verbal encouragement provided throughout the trial. Elapsed time and distance data were visually available so that cyclists could pace themselves.

**Heavy-Intensity Strength Exercise Test.** To identify the actual 5RM load, cyclists performed 5 attempts of 5RM. After a standard, leg press, exercise warm-up, the estimated 5RM load obtained during the familiarization session was used as the first attempt. Thereafter, loads were progressively increased across the attempts until the failure of concentric

action. The attempts were interspersed by 5-minute rest intervals, and verbal encouragement was provided to ensure attainment of maximal values.

**Twenty-Kilometer Time Trial Sessions.** Before each TT<sub>20km</sub>, cyclists were monitored for a 2-minute baseline period during which  $\dot{V}O_2$  and blood lactate concentrations (BLC) were obtained. After the baseline measures, cyclists either performed

the experimental (a standard leg press warm-up followed by 4 sets of 5RM leg press exercise) or control condition (resting for an equal period of ~10 minutes). Thereafter, they performed a 2-stage, standard, cycling warm-up and completed the TT<sub>20km</sub>. A 10-minute interval was used between the heavy-intensity strength exercise bouts or control session and the TT<sub>20km</sub> as an 8–12-minute rest interval, which have been suggested to adequately induce potentiation effects (26). The standard cycling warm-up consisted of 3 minutes of self-paced and 2 minutes of controlled-pace (workload set at 100 W, pedal cadence of 80 rpm, and fixed gear ratio) cycling exercise during which  $\dot{V}O_2$  and BLC were obtained. This experimental approach was defined during a pilot study and was used to provide a cycling economy index (i.e., the  $\dot{V}O_2$  measured at 100 W and 80 rpm). Furthermore, this cycling warm-up design allowed cyclists to readapt themselves to the mechanics of cycling after the heavy-intensity strength exercise bouts in the experimental condition.

Immediately after the controlled-pace warm-up, although the cyclists were still cycling at 100 W (80 rpm and fixed gear ratio), the TT<sub>20km</sub> started and they were freely to change the pedal cadence and gear ratio. Cyclists were instructed to complete the trial in as fast a time as possible similar to that undertaken in the familiarization session.

Feedback was limited to distance updates every 0.5 km at which they were asked to rate their RPE using a 6–20 Borg scale (2). Power output (W), pedal cadence (rpm), and  $\dot{V}O_2$  were continuously recorded throughout the trial, whereas 25  $\mu$ L blood samples were drawn from the ear lobe every 2 km to determine the BLC.

**Statistical Analyses**

**Performance.** For the control and experimental conditions,

**TABLE 2.** Mean physiological and RPE responses (mean ± SD) during the TT<sub>20km</sub> in both the control and potentiation condition.\*†

Variables	Control	Potentiation	% of control	<i>p</i>
$\dot{V}O_2$ (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	43.2 ± 5.9	44.3 ± 10.2	+2.7	0.75
BLC (mmol·L <sup>-1</sup> )	6.6 ± 2.4	6.3 ± 3.20	-3.5	0.93
RPE (AU)	14.6 ± 2.0	14.0 ± 1.9	-3.8	0.76

\*BLC = blood lactate concentration; RPE = ratings of perceived exertion.  
 † $\dot{V}O_2$  is the mean of oxygen uptake throughout the trial; BLC is the mean blood lactate concentration throughout the trial; RPE is the mean rating of perceived exertion throughout the trial.

**TABLE 3.** Power output and pedal cadence responses in the control and potentiation condition according to the initial, intermediate, and final epoch of the TT<sub>20km</sub>.<sup>\*†</sup>

Epochs	Variables	Control	Potentiation	% of control	$\rho$
Initial	$W_{\text{mean}}$	239.3 ± 61.4	253.1 ± 69.4	+5.8	0.06
	$RPM_{\text{mean}}$	96.6 ± 8.2	96.1 ± 12.8	-0.5	1.00
Intermediate	$W_{\text{mean}}$	244.5 ± 67.1	251.3 ± 64.0	+2.7	0.33
	$RPM_{\text{mean}}$	95.3 ± 11.4	96.9 ± 14.8	+1.6	1.00
Final	$W_{\text{mean}}$	288.2 ± 72.4	290.6 ± 76.3	+0.8	0.69
	$RPM_{\text{mean}}$	97.5 ± 10.6	94.1 ± 12.1	-3.4	1.00

<sup>\*</sup>TT<sub>20km</sub> = 20-km time trial.

<sup>†</sup> $W_{\text{mean}}$  is the mean power output of the indicated phase in the TT<sub>20km</sub>;  $RPM_{\text{mean}}$  is the mean pedal cadence of the indicated phase in the TT<sub>20km</sub>.

the time to complete the TT<sub>20km</sub> was used as the performance parameter. Furthermore, the mean power output ( $W_M$ ) in addition to the mean pedal cadence ( $RPM_M$ ) was examined for performance analyses as different pedal cadences may accomplish a given power output (15). All performance parameters were compared between groups (control × experimental condition).

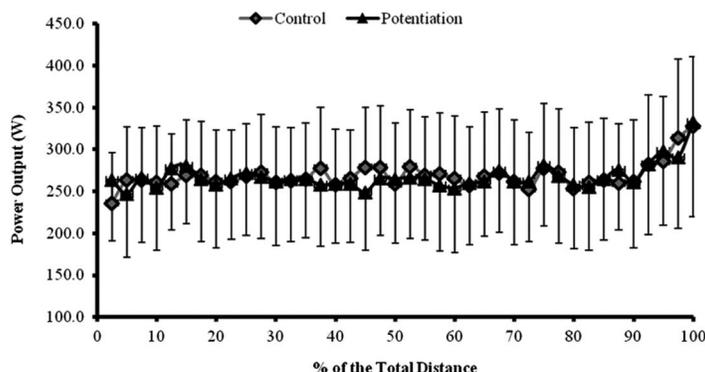
**Pacing Strategy.** To determine if prior high-intensity strength exercise bouts would influence the power output distribution (and pedal cadence) during the time trial (i.e., the pacing strategy), a “J- or U-shaped” curve was assumed for power output data, and the pacing strategy was assessed according to 3 different epochs: (a) the first 10% of the TT<sub>20km</sub> (i.e., epoch from 0- to 2-km), (b) intermediate 80% of the TT<sub>20km</sub> (i.e., epoch from 2- to 18-km), (c) and last 10% of the TT<sub>20km</sub> (i.e., epoch from 18- to 20-km). This analysis was based on the fact that cyclists usually adopt a J- or U-shaped power output distribution during a TT<sub>20km</sub> (20,24). Therefore, we hypothesized that anal-

yses based on 3 different epochs would facilitate the location of potentiation effects in the power output and pedal cadence curves (i.e., pacing strategy). Thus, the  $W_{\text{mean}}$  and  $RPM_{\text{mean}}$  relative to each epoch were calculated and compared with a group × repeated measures design (i.e., control × experimental conditions and initial, intermediate × final epochs). In addition, power output throughout the TT<sub>20km</sub> and at the different epochs was expressed as  $W_{\text{peak}}$  relative values (%  $W_{\text{peak}}$ ).

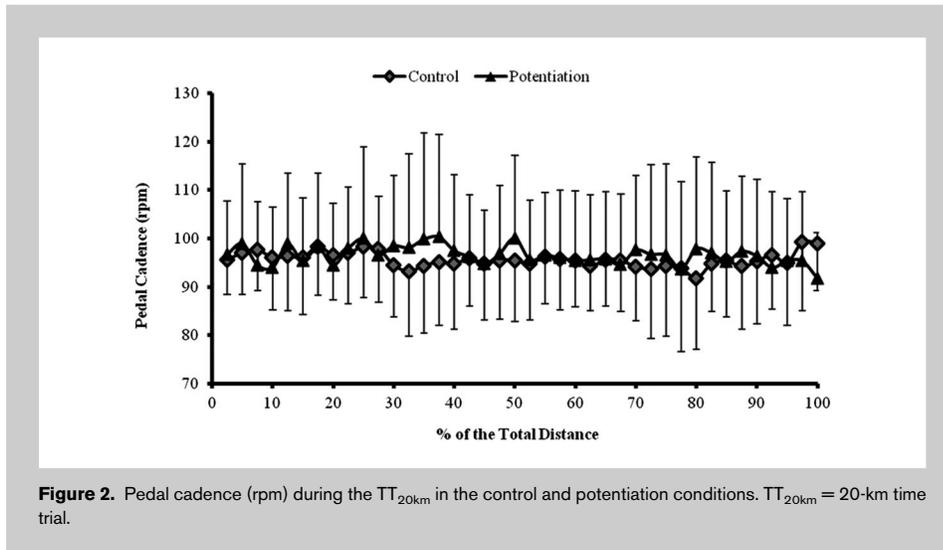
**Cycling Economy.** Breath-by-breath  $\dot{V}O_2$  data (Metalyzer 3B; Biophysic, Cortex) obtained during the 2-minute controlled-pace cycling warm-up (i.e., workload set at 100 W and pedal cadence of 80 rpm) were converted to 10-second averages using specific software (MetaSoft 3.3; Biophysic, Cortex). Thereafter, the mean  $\dot{V}O_2$  during the last 30 seconds was used as a cycling economy index ( $\text{ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ). We acknowledge that submaximal exercise bouts from 4 to 10 minutes have been suggested to measure cycling economy (7). However, in this study, a shorter exercise bout of a 2-minute sub-anaerobic threshold workload was used to provide a cycling economy index while preserving possible potentiation effects derived from the 5RM strength exercise bouts. The cycling economy index was compared between groups (control × experimental condition).

**$\dot{V}O_2$ , Blood Lactate Concentrations, and Ratings of Perceived Exertion Responses.** In addition to the  $\dot{V}O_2$  and BLC baseline values, breath-by-breath  $\dot{V}O_2$  and BLC data were obtained throughout the trials. After converting breath-by-breath  $\dot{V}O_2$  data to 10-second averages, the mean  $\dot{V}O_2$ , BLC, and RPE responses during the TT<sub>20km</sub> were calculated for both the control and experimental conditions. The responses of these variables were compared between control and experimental conditions.

Data distribution was previously checked with Shapiro-Wilk test. Results were reported as mean ± SD to allow comparisons with other studies. Performance parameters such as time to complete the TT<sub>20km</sub>,  $W_M$ , and  $RPM_M$  presented a non-Gaussian distribution so that



**Figure 1.** Power output (W) during the TT<sub>20km</sub> in the control and potentiation conditions. TT<sub>20km</sub> = 20-km time trial.



between-group comparisons were performed with Wilcoxon's test. Accordingly, Friedman's analysis of variance with post hoc Wilcoxon's tests were used to examine 2 groups × 3 epoch repeated measures. Thus, mean power output and pedal cadence in initial, intermediate, and final epoch were compared within group as well as between control and experimental conditions. Comparisons of the mean  $\dot{V}O_2$ , BLC, and RPE between control and experimental session were carried out with a paired Student's *t*-test as these variables showed a Gaussian distribution. The statistical significance was set at 5% ( $p \leq 0.05$ ), and significant results were accepted when reaching power and effect size of  $\geq 0.60$  and intraclass correlations of  $\geq 0.90$ . Statistical analysis was performed with SPSS (SPSS 19.0; IBM, USA) and the freely available G-Power software.

## RESULTS

Baseline  $\dot{V}O_2$  and BLC values obtained before the TT<sub>20km</sub> were  $5.0 \pm 1.2 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$  and  $1.3 \pm 0.3 \text{ mmol}\cdot\text{L}^{-1}$  for the control condition, and  $5.1 \pm 1.1 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$  and  $1.6 \pm 0.4 \text{ mmol}\cdot\text{L}^{-1}$  for the experimental condition, respectively. There was no significant difference between these conditions ( $p > 0.05$ ).

### Cycling Economy

The mean  $\dot{V}O_2$  responses during the last 30 seconds of the controlled-pace cycling warm-up at 100 W (and pedal cadence of 80 rpm) suggested that cyclists increased the cycling economy ( $p < 0.01$ ) after the heavy-intensity strength exercise bouts ( $18.6 \pm 2.5 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ) when compared with the control condition ( $21.3 \pm 8.7 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ).

### Performance

The time to complete the TT<sub>20km</sub> was significantly reduced ( $\sim 6.1\%$ ) for the experimental condition ( $p \leq 0.05$ ) despite the absence of differences for the remaining performance parameters such as  $W_{\text{mean}}$  and  $\text{RPM}_{\text{mean}}$  (Table 1). Further-

more,  $W_{\text{mean}}$  was  $83.0 \pm 253.8\% W_{\text{peak}}$  and  $85.5 \pm 245.1\% W_{\text{peak}}$  for the control and experimental conditions, respectively.

### $\dot{V}O_2$ , Blood Lactate Concentrations, and Ratings of Perceived Exertion Responses

Neither the mean  $\dot{V}O_2$  nor mean BLC during the TT<sub>20km</sub> was different ( $p > 0.05$ ) between control and experimental conditions (Table 2). Accordingly, mean RPE responses were not different ( $p > 0.05$ ) between these conditions (Table 2).

### Pacing Strategy

Analyses of pacing strategy showed that cyclists adopted a J-shaped power output for both conditions (i.e., control and experimental conditions) as a main epoch effect ( $p \leq 0.05$ ) was observed. Thus, the final epoch was greater than the initial and intermediate epochs. On the other hand, no phase × condition interaction effects were observed with the prior 5RM heavy-intensity strength exercise bouts, not modifying the power output (Figure 1) distribution during the TT<sub>20km</sub>. Thus, control and experimental conditions produced similar values in the initial, intermediate, and final epochs of the TT<sub>20km</sub> ( $p > 0.05$ ). However, a trend ( $p = 0.06$ ) for a higher mean power output during the first 10% of the trial (i.e., initial epoch) was observed for the experimental condition (Table 3). When expressed as a percentage of the  $W_{\text{peak}}$  obtained in the incremental cycling test, the power output for the control and experimental conditions was  $80.3 \pm 230.8\% W_{\text{peak}}$  and  $84.9 \pm 260.9\% W_{\text{peak}}$  in the initial epoch,  $82.3 \pm 252.3\% W_{\text{peak}}$  and  $84.3 \pm 240.6\% W_{\text{peak}}$  in the intermediate epoch and  $96.7 \pm 272.2\% W_{\text{peak}}$  and  $97.5 \pm 286.8\% W_{\text{peak}}$  in the final epoch, respectively.

Accordingly, the pedal cadence (Figure 2) was not affected by the prior 5RM heavy-intensity strength exercise bouts.

## DISCUSSION

The aim of this study was to verify if prior heavy-intensity strength exercise bouts would alter the power output and improve the cycling performance in a subsequent TT<sub>20km</sub>. We had hypothesized that prior 5RM leg press exercise bouts may increase the power output and reduce the time to complete a TT<sub>20km</sub>. Overall, results of this study provide some support to our initial hypothesis, indicating that preceding 5RM strength exercise bouts were effective in improving the subsequent cycling performance.

When compared with the control condition, we found a significant 6.1% reduction in the time to complete the

$TT_{20km}$  after the 5RM leg press exercise despite the absence of significant effects in the mean power output over the trial ( $W_{mean}$ ). It was difficult to compare these results with others as only 1 study by Parry et al. (19) investigated the influence of prior conditioning exercises, comprised of strength exercise bouts, on subsequent cycling performance. In their study, Parry et al. (19) found a nonsignificant effect of back squats at 30 and 90% of 1RM on the 30-second all-out cycling performance. Some aspects that may account for differences are discussed below.

Firstly, we used a 10-minute rest interval between the 5RM exercise bouts and the  $TT_{20km}$ , whereas Parry et al. (19) used a 20-minute interval. Intervals between 8 and 12 minutes have been suggested to adequately induce potentiation effects as a result of the preceding conditioning exercise (26). A range from 8 to 12 minutes is proposed as an adequate rest interval, favoring a positive balance between potentiation and residual fatigue effects derived from the conditioning exercise (23,25). Thus, it is possible that the time interval used in this study maximized the appearance of a potentiated performance in the subsequent cycling time trial test. Longer rest intervals may reduce or abolish any potentiation effect (23,15).

Secondly, instead of a 30-second all-out cycling test (19), we used a  $TT_{20km}$  as the principal cycling exercise assessment because we aimed to examine a usual cycling performance measure. In this study, cyclists completed the  $TT_{20km}$  within 28.1 and 26.6 minutes for the control and experimental conditions, respectively. The appearance of potentiation effects after heavy-intensity strength exercise bouts in this study may have resulted from prolonged cycling time trial applied, which use lower anaerobic performance reserves when compared with a 30-second all-out cycling test (17). This suggestion is based on the fact that a 30-second all-out cycling test is performed at supramaximal power output values such as  $\geq 200\%$  of the  $W_{peak}$  so that individuals use all-out pacing strategies to access all available anaerobic performance reserves throughout (27). In contrast, lower anaerobic performance reserve is accessed during a  $TT_{20km}$  as submaximal power output values (i.e.,  $\leq 90\%$  of the  $W_{peak}$ ) are generated during the trial. During a  $TT_{20km}$ , cyclists use a J-shaped pacing strategy, and therefore achieve power output values were similar to  $W_{peak}$  values at final epochs (1). Perhaps, the improved  $TT_{20km}$  performance after heavy-intensity strength exercise bouts in this study occurred through increased capacity to exploit anaerobic performance reserves during the cycling trial (20). Future studies are needed to verify this hypothesis.

Thirdly, we used heavy resistance loads (e.g., 5RM) with multiple sets as the strength exercise in this study. However, Parry et al. (19) used 5 squat repetitions at 30 and 90% of 1RM interspersed with 2-minute rest. Thus, aspects such as intensity, volume, type of contraction (dynamic  $\times$  isometric), and muscle fiber recruitment (type 1 vs. type 2) of the preceding strength exercise may have influenced these re-

sults (6,11,21). Finally, instead of rugby players (19), the athletes examined in this study were well-trained cyclists experienced in cycling time trials. Given the different training backgrounds between these individuals (cycling vs. weightlifting), it is possible that the experience with cycling exercises have influenced the cycling performance responses after prior heavy-intensity strength exercise bouts in both the studies.

Interestingly, significant changes in the time to complete the  $TT_{20km}$  were not followed by significant changes in the power output or pedal cadence. However, it is worth noting that the mean power output in the first 10% of the  $TT_{20km}$  (i.e., initial epoch) tended to be significantly greater (5.8%;  $p = 0.06$ ) after the heavy-intensity strength exercise bouts. The significant 6.1% improvement in the time to complete the  $TT_{20km}$  after the conditioning exercise may have been because of an associated but statistically insignificant 5.8% increase in the initial power output. This increase could have been because of the hyperbolic relationship between power output, pedal cadence, and velocity during pedaling with minimal changes in 1 parameter possibly affecting the others (15).

Altered cycling economy could have also influenced the  $TT_{20km}$  performance after the preceding heavy-intensity strength exercise bouts. Although our results must be interpreted with caution as a 2-minute cycling exercise bout that was used to obtain a cycling economy index, greater cycling economy in the potentiated condition (i.e., experimental condition) may have resulted of a different pedaling technique after the heavy-intensity strength exercise (12). In fact, there was a lower  $\dot{V}O_2$  during the controlled-pace, cycling, warm-up at 100 W and pedal cadence of 80 rpm during the experimental condition. However, the complex interplay between metabolic and mechanical factors during cycling (4) requires further studies to better understand the relative influence of these factors for the potentiated cycling performance.

Analyses of the 3 different epochs of the  $TT_{20km}$  showed that cyclists adopted a similar J-shaped pacing strategy in both the control and experimental conditions (Figure 1). Therefore, it may be suggested that preceding heavy-intensity strength exercise bouts did not change the J-shaped pacing profile despite the trend for a greater power output during the first 10% of the trial. Furthermore, this slight alteration in pacing strategy at the start of the trial in the experimental condition may be related to the greater variability observed in power output at the start of cycling trials (20,24). However, the appropriate dose of heavy-intensity strength exercise to induce significant effects in cycling pacing strategy remains unknown.

Despite the different  $TT_{20km}$  performances for the control and experimental conditions, there was no difference in the physiological and RPE mean responses. Typical  $\dot{V}O_2$  and BLC responses for a cycling  $TT_{20km}$  were observed in the control and experimental conditions (24). Likewise, RPE

showed a typical linear response in both the conditions. These similar results between conditions may indicate that cyclists were able to produce a greater initial power output for a matched psycho-physiological stress and complete the TT<sub>20km</sub> in a shorter time in the potentiated performance (i.e., experimental condition).

In conclusion, results of this study show that prior heavy-intensity, strength exercise, 5RM leg press exercise bouts significantly improved the cycling performance for a subsequent TT<sub>20km</sub> with no alteration in pacing strategy. Additional studies are required to better understand how mechanical and metabolic (i.e., cycling economy) factors are related to the potentiated cycling performance after heavy-intensity, strength exercise bouts.

### PRACTICAL APPLICATIONS

These results have practical implications as they suggest that acute interventions with heavy-intensity strength exercises could potentiate the performance of a subsequent cycling time trial. Such results may be relevant for coaches and athletes as a significant 6.1% improvement that was observed in the TT<sub>20km</sub> performance when cyclists performed 5RM leg press exercise bouts before the cycling time trial. This difference is relevant for competitive cycling events as it could differentiate between final positions in a competitive cycling race. For example, in cycling time trials with similar distances (~20 km), elite athletes can produce a mean power output of 362 ± 59 W (15), whereas a 6.1% of improvement would lead to a mean power output of 384 W and a shorter completion time. Therefore, heavy-intensity strength exercise bouts may be strategically planned to be included within warm-up routines for specific cycling training sessions and competitions. For example, a “complex warm-up strategy” involving heavy-intensity strength exercises may be incorporated into a warm-up routine for individual or team speed cyclists, competing short pursuit trials, individual time trials, or short stages of long-term competitions such as the Tour de France.

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