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Original Article

Sprint cycling: current practice and motivational considerations for performance recovery

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Abstract:

The time between races varies in the track cycling competition known as the Match Sprint, but can be as little as 10-15 minutes. Both physiological and motivational factors could affect performance recovery. This study investigated how the between-sprint recovery activity, and an alteration in the duration of the second sprint, affected performance. Twenty-four strength-trained men (age: 26 ± 5 years; height: 180.3 ± 6.1 cm; body-mass: 82.3 ± 6.9 kg) participated. During each of the four experimental trials, two sprints were performed 12 minutes apart. The first was always 18 s and the second was either 9 s or 18 s. Between sprints, passive rest or a mixture of active and passive recovery was undertaken. Peak power output (PPO), as well as mean power output over 9 s (MPO_9) and 18 s (MPO_{18}), was recorded. Lactate concentration, ratings of sprint preparation and performance, as well as perceptions of recovery, were also measured. Post-trial and post-study questionnaires explored factors that may have influenced performance. A sprint number × recovery method interaction ($F_{(1,23)} = 28.791$, $p < 0.001$, $\eta_p^2 = 0.556$) was found for PPO, with a significantly lower PPO in sprint 2 following passive recovery. Sprint number × second sprint duration interactions were found for PPO ($F_{(1,23)} = 9.867$, $p = 0.005$, $\eta_p^2 = 0.300$) and MPO_9 ($F_{(1,23)} = 8.922$, $p = 0.007$, $\eta_p^2 = 0.279$). A significant time × condition interaction was also found for lactate concentration ($F_{(6.082,97.320)} = 2.982$, $p = 0.010$, $\eta_p^2 = 0.157$), although post hoc tests were unable to identify the cause of any of these effects. Typically, the participants were satisfied with their sprint performances and expressed positive views about the recovery activity undertaken. The main finding was, therefore, that PPO was lower following passive recovery, but the effects on MPO were not apparent.

Keywords: Active Recovery, Pacing, Passive Recovery, Repeated Sprints, Track Cycling

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Conflict of Interest

The authors declare that they have no known financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Publication Ethics

Written informed consent was obtained from all participants. The study was granted approval by St Mary's University Ethics Committee.

Authorship

All authors contributed to the conceptualisation of the project, methodological design, provided additional resources, supervision, and reviewed/edited the written work.

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INTRODUCTION

At the 2020 Tokyo Olympics, the sprint cycling disciplines on the track were the Team Sprint, the Keirin, and the Match Sprint. The Match Sprint consists of a qualifying time-trial (the Flying 200), followed by head-to-head races, whereby two riders will compete against each other in a bid to cross the finish line first. Whilst each race takes place over three laps of the track, the actual distance that the riders maximally sprint is not fixed (Dale et al., 2022). Air resistance is a major limiting factor in cycling performance (Faria, 1992). Reductions in air resistance can be achieved by closely following another rider (Craig & Norton, 2001), meaning that riders may attempt to strategically force their opponent to take the lead in this highly tactical event. The recovery time between races also varies. The average within session recovery period at the Tokyo Olympics was 48 ± 23 minutes, and in the final Gold Medal decider, the riders had just over 15 minutes to recover from their previous heat (Dale et al., 2022). At the 2016 Rio Olympics, the schedule indicated that a recovery period as short as 10 minutes may have occurred (Vieria, 2016). In laboratory-based tests, both peak (PPO) and mean (MPO) power output have been found to be reduced when 12 minutes separated two 18 s cycling sprints (Dale et al., 2022). Possible explanations for the loss of performance in the second sprint could be because the participants rested passively on the ergometer between sprints (Dale et al., 2022) or could be as a result of a change in pacing strategy.

Passive rest may not be reflective of the current practice that is undertaken by sprint cyclists (Dale et al., 2022), which may include a mixture of active and passive recovery (personal communication, 12th September, 2019). The rationale for performing an active recovery could be to increase blood flow to the muscle, enhancing oxygen delivery thereby aiding PCr resynthesis, as well as improving the removal of lactate and hydrogen ions (Bogdanis et al., 1996b). The production of lactate and hydrogen ions will occur during intense exercise and whilst the implications for muscular fatigue continue to be debated (Fitts, 2016; Westerblad, 2016), the inter- and intra-cellular movement of lactate is driven by concentration or pH gradients, or by redox state (Brooks, 2018). The majority of lactate metabolism is directed towards oxidation (Brooks, 2018). Cardiac muscle is highly oxidative making it a major lactate consumer (Gladden, 2008). However, skeletal muscles will also oxidise lactate, with the oxidation rate being dependent on the metabolic rate of both the exercising and resting muscles (Gladden, 2008). Whilst not all findings have been in support (Bogdanis et al., 1996b; Dorado et al., 2004), the majority of research has indicated that performing an active recovery does improve lactate clearance (Devlin et al., 2014; Kirkpatrick & Burrus, 2020; McLellan & Skinner, 1982; Menzies et al., 2010).

From a sprint cycling performance perspective, when two 30 s Wingate tests were performed 15 minutes apart, lactate clearance was enhanced when an active recovery was undertaken, but no significant interactions were found for any of the performance measures (absolute PPO, relative PPO, MPO, relative MPO, total work, and fatigue index) (Kirkpatrick & Burrus, 2020). The participants were, however, recreationally active females. Sprint performance recovery may be faster in females than males, albeit this may relate to the higher power outputs that are typically produced by males, rather than a difference in fatigue resistance between sexes (Billaut & Bishop, 2012). In the study by Kirkpatrick and Burrus (2020), the PPO achieved in the first sprint was on average ~ 730 W. In contrast, an average PPO of just under 1300 W was reported for recreational active males, during the first of two 30 s cycling sprints (Bogdanis et al., 1996b). When a second sprint was undertaken four minutes after the first, an active recovery resulted in a significantly greater restoration of MPO (Bogdanis et al., 1996b). Furthermore, the improvement in performance recovery was as a result of the power generation during the first 10 s of the second sprint (Bogdanis et al., 1996b), where a disproportionate amount of the work is conducted (Bogdanis et al., 1996a).

PPO usually occurs a few seconds after a sprint is initiated (de Jong et al., 2015; Glaister et al., 2019; Wittekind et al., 2011), with power output declining thereafter. The optimal sprinting strategy has, therefore, been described as using an all-out approach (Abbiss & Laursen, 2008). There is, however, evidence to suggest that pacing does still exist during single- (de Jong et al., 2015; Glaister et al., 2019; Wittekind et al., 2011) and repeated-sprints (Billaut et al., 2011). During single-sprints, even though the time to PPO was unaltered, a lower PPO has been found when longer sprints were undertaken (de Jong et al., 2015; Glaister et al., 2019; Wittekind et al., 2011). During repeated-sprints, in comparison to a control trial, where the participants were correctly informed that they would be required to perform ten

6 s sprints with 24 s of recovery, power output was significantly higher during the first sprint, as well as the cumulated work over the first five sprints, in the deception trial, where the participants believed that they were only going to perform five sprints (Billaut et al., 2011). Therefore, the perception that the participants had about the demands of the task, may have affected the amount of effort that they were willing to exert. The maximum effort that an individual is prepared to provide to complete a task has been termed their potential motivation and forms part of the psychobiological model (Marcora, 2008). Other factors that have been included in the model include: perception of effort; knowledge of the distance or time needed to complete a task; knowledge of the distance or time remaining; and previous experience of the effort required for exercise of different intensities and durations (Pageaux, 2014). The psychobiological model was, however, developed considering endurance exercise (Marcora, 2008), meaning that its applicability to short-duration all-out tasks is not known. Nonetheless, given the aforementioned findings of pacing during sprint and repeated-sprint activities, it is conceivable that many of its elements could be relevant.

The aim of the current study was, therefore, to investigate how the between-sprint recovery activity that is currently undertaken by sprint cyclists (a mixture of active and passive recovery) affected performance, as well as to evaluate whether a change in second sprint duration provided evidence of an alteration in pacing strategy. It was hypothesised that performing a mixture of active and passive recovery between sprints would enhance the recovery of all of the performance measures. It was also hypothesised that performance recovery would be greater when a shorter duration second sprint was undertaken.

METHODS

Participants

Twenty-four men (age: 26 ± 5 years; height: 180.3 ± 6.1 cm; body-mass: 82.3 ± 6.9 kg), who were regularly conducting resistance training (at least two sessions per week for the last six months), volunteered to take part in this study. The sample size was determined considering previous research

(Billaut et al., 2011; Bogdanis et al., 1996b; Dale et al., 2022; de Jong et al., 2015; Glaister et al., 2019; Kirkpatrick & Burrus, 2020; Wittekind et al., 2011) and resource constraints. To aid with the consistency in testing conditions, the participants were instructed to refrain from conducting any strenuous exercise for 24 hours, ingesting alcohol and caffeine for 12 hours, and consuming food for three hours, prior to each trial. Before commencing the first trial, a pre-activity readiness questionnaire was completed, providing a screening process for any existing medical conditions and/or injuries that could have affected the ability of the participants to sprint on the cycle ergometer. Written informed consent was obtained and the participants were advised about the risks and benefits of taking part in the study. Ethical approval was granted by St Mary's University Ethics Committee (London, United Kingdom), code of approval: SMUETHICS202223254.

Apparatus and Materials

A stadiometer, weighing scales, and skinfold callipers were used to collect anthropometric measurements. For all sprints, the cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands) was put in Wingate mode, with the torque factor set to 0.95 $Nm \cdot kg^{-1}$. The torque factor was greater than the standard Wingate test torque factor, as strength-trained individuals require a greater resistance to optimise sprint performance (Pazin et al., 2011). A £100 gift voucher (Amazon, Seattle, USA) was rewarded to the participant that produced the highest MPO relative to body-mass over all sprints in the experimental trials. An automated analyser (Biosen C-Line, EFK Diagnostics, Barleben, Germany) was used to measure lactate concentration. Software for calculating blood lactate markers (Newell et al., 2007) was used to identify the first rise in blood lactate concentration (LT) via the log-log LT method, as well as to determine the corresponding power output. Visual analogue scales (VAS) were used to assess preparedness to sprint (prior to each sprint), perceptions of recovery (between sprints), and sprint performance rating (after each sprint). The preparedness to sprint scale ranged from '*not at all*', indicating that the participant did not feel at all prepared to perform their best maximal effort 18 s sprint, to '*completely*', suggesting that they felt totally prepared to perform their best possible maximal effort 18 s sprint. The sprint performance scale ranged from '*poor'*, a very bad reflection of their best sprint performance, to '*optimal*', an excellent reflection of their best sprint performance. Finally, the perceptions of recovery scale ranged from '*not at all recovered*', reflective of their recovery status at the end of the first sprint, to '*completely recovered*', suggesting that they believed that they could perform another maximal effort 18 s sprint, matching their previous effort. A post-trial questionnaire was completed at the end of each of the experimental trials. The questionnaire asked how satisfied the participants were with their sprint performances that day, what they felt may have mostly influenced their performances, and how they felt the recovery activity affected their second sprint performance. After the final trial, an additional questionnaire was completed. The end-of-study questionnaire asked the participants why they chose to participate, what factors they felt had mostly influenced their approach to the sprints, and the extent to which the offer of a financial reward had affected their approach to the sprints.

Procedures

Trial 1

Anthropometric measurements were first taken. Skinfold thickness was measured at the biceps, triceps, subscapular, and suprailliac, and was used to estimate body-fat using a recognised formula (Durnin & Womersley, 1974). The cycle ergometer was then adjusted for each participant, with the setup (seat and handlebar height, as well as fore-aft positions) being recorded to facilitate replication during the subsequent trials. Next, the participants performed a step test (starting load 40-100 W, step change 20 $W \cdot stage^{-1}$) on the ergometer. Stages were three minutes long and at the end of each stage a 20 µl capillary blood samples was taken from the earlobe. The test was stopped when blood lactate concentration reached ~ 4 $mmol \cdot L^{-1}$. A brief rest period (~ 5 minutes) followed the step test. During the rest period, the participants were asked to view the three VAS. The participants were advised that there were no right or wrong responses to any of the scales and that they should place a mark that best represented their feeling at that time. Following confirmation from the participants that they understood the requirements of each scale, they got back on the cycle ergometer, before being asked to indicate which leg they would prefer to use to initiate a stationary start sprint. Each sprint began with the chosen leg being ~ 45° forward to the vertical axis, which was consistent with previous research (Billaut & Basset, 2007; Dale et al., 2022). The sprint warm-up protocol (see Table 1) was then explained and undertaken. The same sprint warm-up protocol was used in all the experimental trials. Three minutes after the sprint warm-up, the participants performed a 9 s familiarisation sprint. Following an additional 5 minutes of rest (2 minutes of active cycling, 3 minutes passively seated on the ergometer), an 18 s familiarisation sprint was performed. For all sprints, the participants were instructed to provide a maximal effort from the start, to remain seated throughout, and to keep sprinting until the resistive load was removed. Strong verbal encouragement was provided during each sprint. Positive statements were used to aid performance, e.g. *'push, push, push'* on sprint initiation, *'you're doing well'* following the initiation, *'dig-in'* at approximately the half-way point, with a time remaining phrase only used towards the end of the sprint, *'last 6 s, keep going'* (Edwards et al., 2018). Practice measurements of the three VAS were also performed. At the end of the trial, the participants were advised about the requirements for winning the gift voucher. Consistent with previous research, the reward was offered to encourage the participants to perform maximally (Marcora & Staiano, 2010).

Table 1 Warm-up and sprint protocol (Coaching and Sports Science Division of the United States Olympic Committee, 2004).

Duration (s)	Resistive Load ($Nm \cdot kg^{-1}$)	Instruction
300	0	Passive rest
120	0.187	Comfortable cadence 60-90 rpm
5 (rolling start sprint)	0.47	Spin as fast as possible
50	0.187	Comfortable cadence 60-90 rpm
5 (rest)	0*	Get into start position
5 (stationary start sprint)	0.47	Drive as hard as possible
50	0.187	Comfortable cadence 60-90 rpm
5 (rest)	0*	Get into start position
5 (stationary start sprint)	0.47	Drive as hard as possible
55	0.187	Comfortable cadence 60-90 rpm
180	0	Passive rest

Note: *prior to each sprint a resistance of 1000 W was briefly applied to stop the flywheel.

Trials 2-5

During each of the four experimental trials, the participants performed two cycling sprints, 12 minutes apart. Capillary blood lactate measurements were taken at rest, following the warm-up, immediately after the first sprint, as well as 3.5, 7.5, and 10.5 minutes after the first sprint. The VAS that evaluated how prepared the participants felt they were to perform an 18 s sprint was presented 30 s prior to each sprint, with the participants being asked to provide a clear mark on the scale with a pen. The scale that assessed how the participants rated their sprint performance was marked immediately after each sprint. The scale that assessed perceived recovery status was presented every 45 s for 10.5 minutes during the period between sprints. Consistent with previous research, a fresh scale was used for each measurement to prevent visual feedback from affecting the response (Glaister et al., 2012). If the participants perceived that their recovery status was complete within 10.5 minutes, the scale was no longer administered. The first sprint was always 18 s long. Following the sprint and the marking of the sprint performance scale, the participants were advised about the recovery condition (passive or active/passive mixed). During the active/passive mixed recovery trials, 30 s after the sprint, the participants cycled for 3.5 minutes at 80% of the LT power output (108 ± 35 W), a recovery exercise intensity that has been suggested to optimise blood lactate clearance (Devlin et al., 2014). The participants then rested passively on a chair for four minutes, before cycling again for a further 3.5 minutes at the same intensity. Following a final 30 s of passive rest, the participants performed a second sprint. The second sprint duration was either 9 s or 18 s. The participants were advised about the duration of the second sprint after the preparedness to sprint scale had been marked. In the passive recovery trials, the participants rested passively on the ergometer during the equivalent active cycling periods. To reduce the possibility of an order effect, the trials were performed in a randomised counterbalanced fashion. This was achieved by constructing a numerical list of every combination that the four experimental conditions could be performed. Each participant was then randomly assigned a unique number between one and twenty-four, which was then matched to the corresponding trial order. At the end of each session, the post-trial questionnaire was completed on a computer and following the final trial, the post-study questionnaire was also completed.

Data Analysis

The cycle ergometer recorded power output at 5 Hz. PPO was the highest value recorded. Mean power output was calculated over the first 9 s (MPO_9), and where appropriate, over the full 18 s (MPO_{18}) of the test. All VAS were 20 cm in length and markings were converted to a percentage before analysis. The time-course of perceived recovery status was modelled using a one-phase exponential growth function (see Equation 1). The mathematical function was selected based on previous research that has modelled physiological responses following a cycling sprint (Glaister et al., 2012). The questionnaire data were inductively organised into domain themes (Meijen et al., 2022).

$$PR(t) = (A_0 * \left(1 - e^{-\frac{(t)}{\tau_0}}\right) * U_0) \qquad \text{(Equation 1)}$$

where *PR(t)* is the perception of recovery percentage at any time-point, A_0 represents the asymptotic amplitude to which the performance recovery percentage projects, τ_0 is the time constant, and t is time. $U_0 = 0$ when $t < 0$ and $U_0 = 1$ when $t \geq 0$.

Statistical Analysis

Statistical analyses were conducted using SPSS® software, version 28.0 (IBM Corporation, Armonk NY; USA). Values are reported as mean ± standard deviation. Statistical significance was set *a priori* at $p < 0.05$. PPO, MPO_9, as well as the preparedness and performance ratings were assessed using a three-way (sprint number × recovery method × second sprint duration) ANOVA. Due to violations of normality, data transformations were performed for the analysis of preparedness (taking the arcsine) and performance (cubing) ratings. Two-way ANOVAs were used to evaluate both differences in MPO_{18} (sprint number × recovery method) and lactate concentration (time × condition). Due to violations of normality, the time constant (τ) derived from the modelled response for perceptions of recovery was transformed by taking the square root. A one-way ANOVA was then used to assess differences in τ between the four conditions. A one-way ANOVA was also used to assess for a performance training effect for PPO, MPO_9 and MPO_{18}. For the evaluation of a training effect, the data were assessed in trial order. The coefficient of variation, the intraclass correlation coefficient (ICC), as well as 95% confidence limits, were also calculated using recommended procedures (Schabort et al., 1999). Where applicable, if the assumption of sphericity was not satisfied, the Greenhouse-Geisser correction was applied. Where required, *post hoc* analyses were conducted using a Bonferroni correction.

RESULTS

Performance

Peak Power Output

A main effect was found for sprint number ($F_{(1,23)} = 30.976$, $p < 0.001$, $\eta_p^2 = 0.574$) and recovery method ($F_{(1,23)} = 19.660$, $p < 0.001$, $\eta_p^2 = 0.461$), with a higher PPO being found during sprint 1 and when a mixed recovery was undertaken. Two-way interactions were found for both sprint number × recovery method ($F_{(1,23)} = 28.791$, $p < 0.001$, $\eta_p^2 = 0.556$) and sprint number × second sprint duration ($F_{(1,23)} = 9.867$, $p = 0.005$, $\eta_p^2 = 0.300$) (see Figures 1 & 2). For the sprint number × recovery method interaction, *post hoc* analyses revealed no significant difference between recovery conditions for sprint 1 PPO, but when compared to a mixed recovery, sprint 2 PPO was significantly lower following passive recovery. For the sprint number × second sprint duration interaction, *post hoc* analyses revealed no significant differences between conditions for either sprint 1 or sprint 2. The three-way interaction for PPO was not significant ($F_{(1,23)} = 0.221$, $p = 0.643$, $\eta_p^2 = 0.010$).

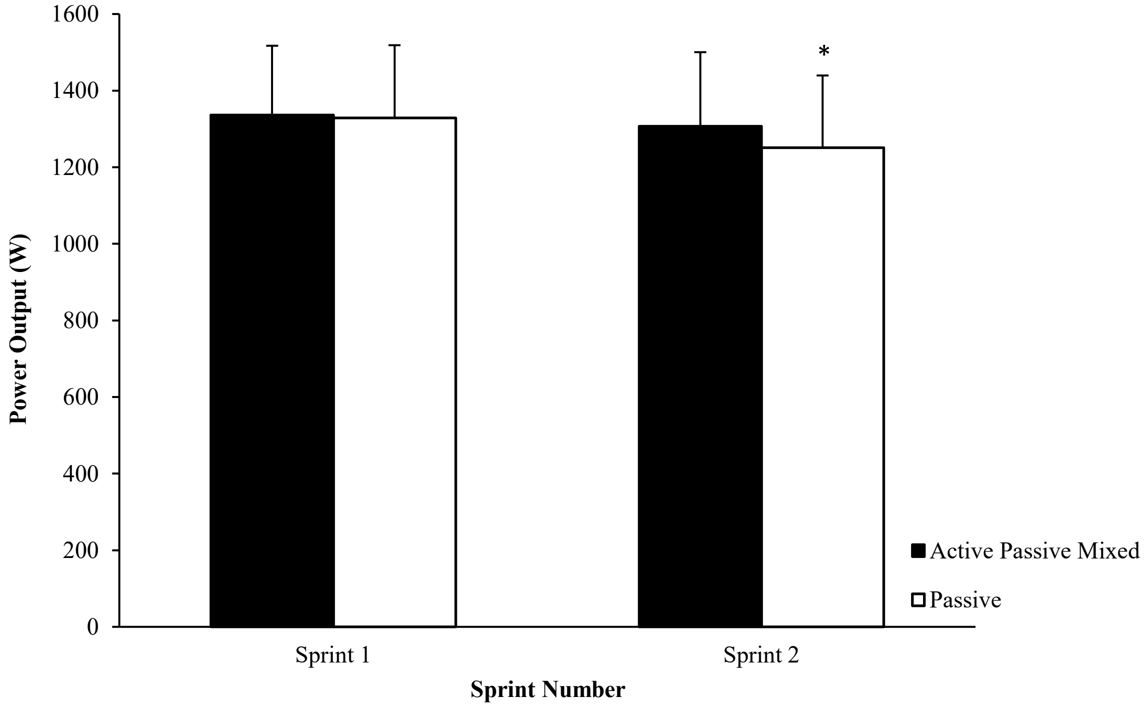

Figure 1 Peak power output during two sprints performed 12 minutes apart. The recovery method was either a mixture of active and passive recovery or just passive recovery. Bars represent the mean and error bars the standard deviation. *denotes a significantly ($p < 0.05$) lower PPO in sprint 2 following passive recovery when compared to a mixture of active and passive recovery.

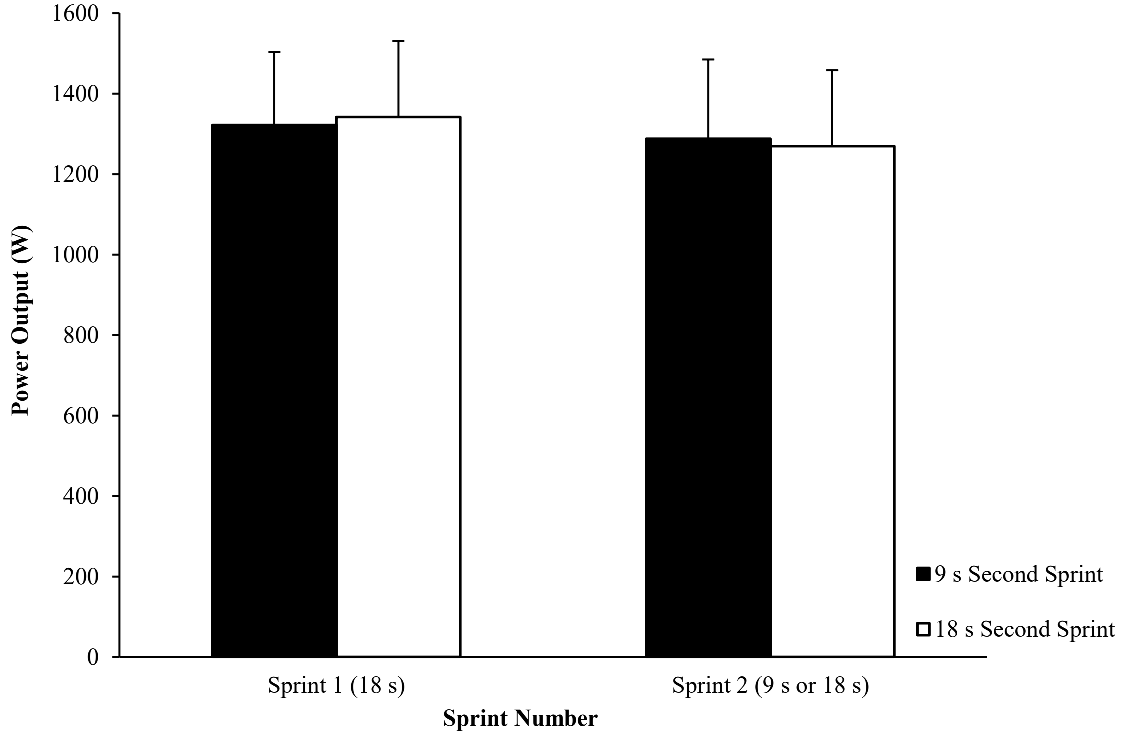

Figure 2 Peak power output during two sprints performed 12 minutes apart. The first sprint was always an 18 s sprint. The second sprint was either 9 s or 18 s. Bars represent the mean and error bars the standard deviation.

9 s Mean Power Output

Main effects were found for sprint number ($F_{(1,23)} = 33.224$, $p < 0.001$, $\eta_p^2 = 0.591$) and recovery method ($F_{(1,23)} = 22.883$, $p < 0.001$, $\eta_p^2 = 0.499$), with a higher MPO_9 being found during sprint 1 and when a mixed recovery was undertaken. A significant interaction was found for sprint number × second sprint duration ($F_{(1,23)} = 8.922$, $p = 0.007$, $\eta_p^2 = 0.279$), although *post hoc* analyses did not reveal a significant difference for either sprint 1 or sprint 2 performances between the conditions (see Figure 3). The two-way interaction for sprint number × recovery method ($F_{(1,23)} = 3.343$, $p = 0.080$, $\eta_p^2 = 0.127$) and the three-way interaction (sprint number × recovery method × second sprint duration) were not significant ($F_{(1,23)} = 0.326$, $p = 0.573$, $\eta_p^2 = 0.014$).

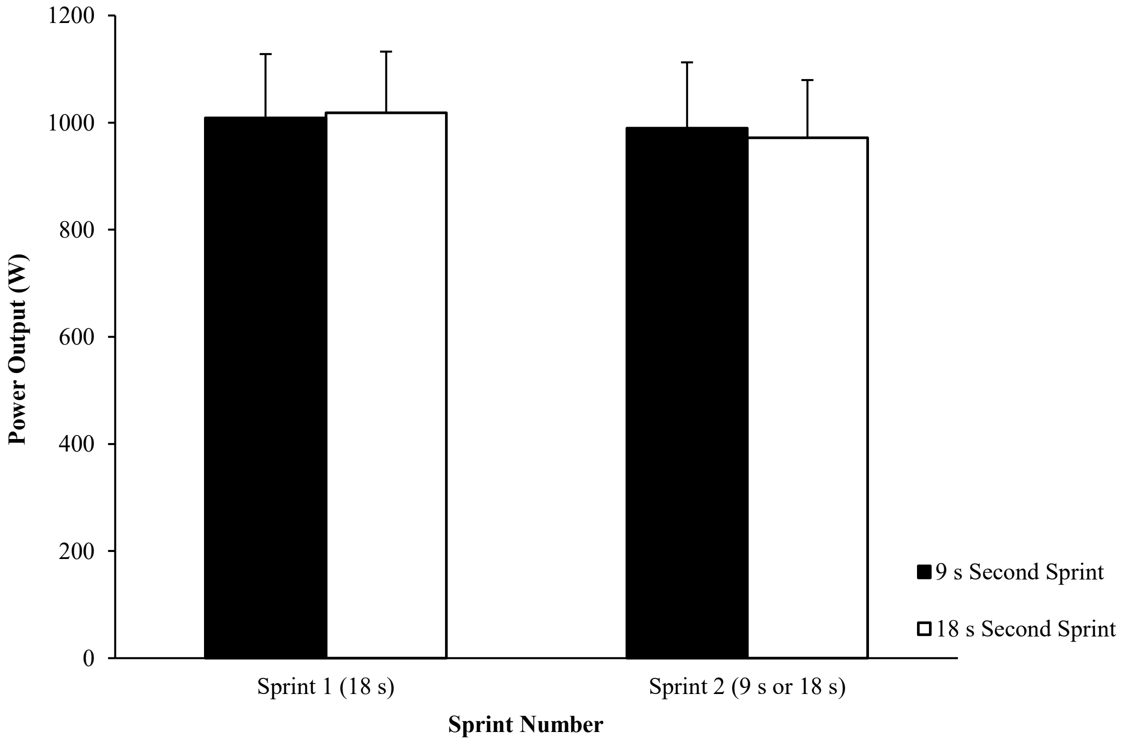

Figure 3 Mean power output during the first 9 s of two sprints performed 12 minutes apart. The first sprint was always an 18 s sprint. The second sprint was either 9 s or 18 s. Bars represent the mean and error bars the standard deviation.

18 s Mean Power Output

Significant main effects of sprint number ($F_{(1,23)} = 39.088$, $p < 0.001$, $\eta_p^2 = 0.630$) and recovery method ($F_{(1,23)} = 10.229$, $p = 0.004$, $\eta_p^2 = 0.308$) were found for MPO_{18}, with a higher MPO_{18} being found during sprint 1 and when a mixed recovery was undertaken. The sprint number × recovery method interaction was not, however, significant ($F_{(1,23)} = 2.513$, $p = 0.127$, $\eta_p^2 = 0.098$) (see Figure 4).

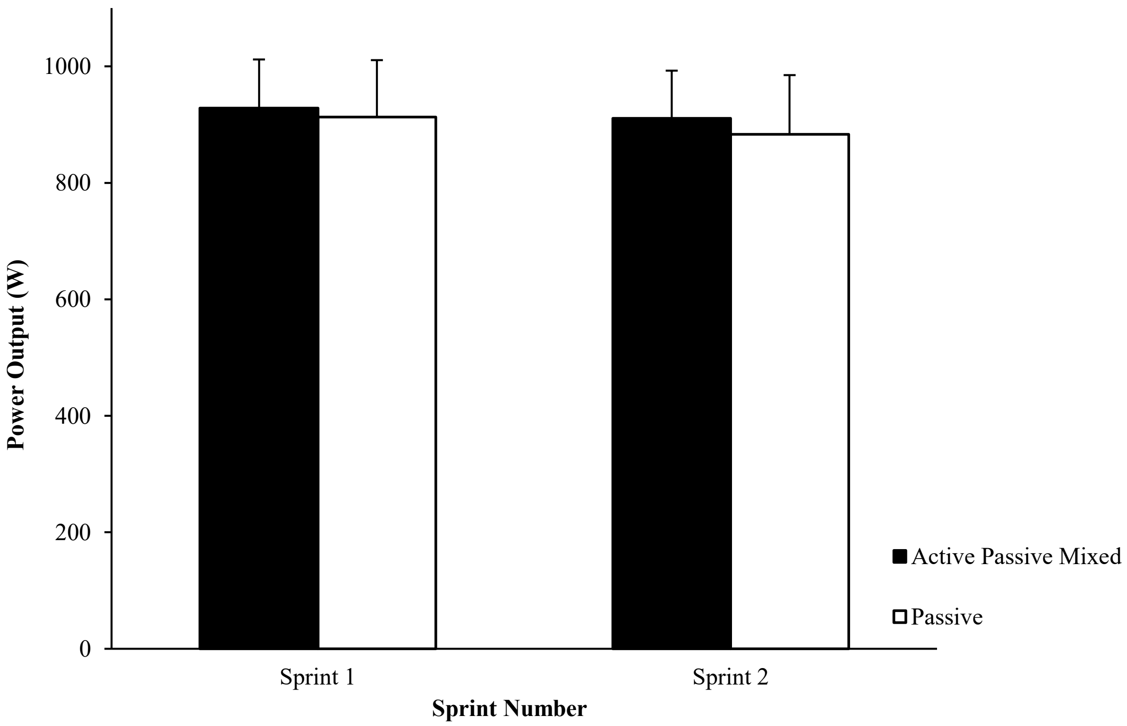

Figure 4 Mean power output during two 18 s sprint performed 12 minutes apart using either a mixture of active and passive recovery or just passive recovery between sprints. Bars represent the mean and error bars the standard deviation.

Sprint Consistency

When analysed in trial order, no significant differences were found for PPO ($F_{(3,69)} = 0.059$, $p = 0.981$, $\eta_p^2 = 0.003$), MPO_9 ($F_{(3,69)} = 0.248$, $p = 0.862$, $\eta_p^2 = 0.011$), or MPO_{18} ($F_{(2.137,49.146)} = 0.598$, $p = 0.565$, $\eta_p^2 = 0.025$). The coefficient of variation and the ICC were 4.7% [4.0 – 5.6] and 0.90 [0.82 – 0.95] respectively for PPO, 4.1% [3.5 – 4.9] and 0.89 [0.80 – 0.94] respectively for MPO_9, and 2.8% [2.4 – 3.4] and 0.93 [0.87 – 0.96] respectively for MPO_{18}.

Blood Lactate Concentration

A significant effect of time ($F_{(1.680,26.872)} = 149.482$, $p < 0.001$, $\eta_p^2 = 0.903$) was found for blood lactate concentration. A significant time × condition ($F_{(6.082,97.320)} = 2.982$, $p = 0.010$, $\eta_p^2 = 0.157$) interaction was also found. However, *post hoc* tests did not reveal any significant differences between conditions at any of the six time-points (see Figure 5).

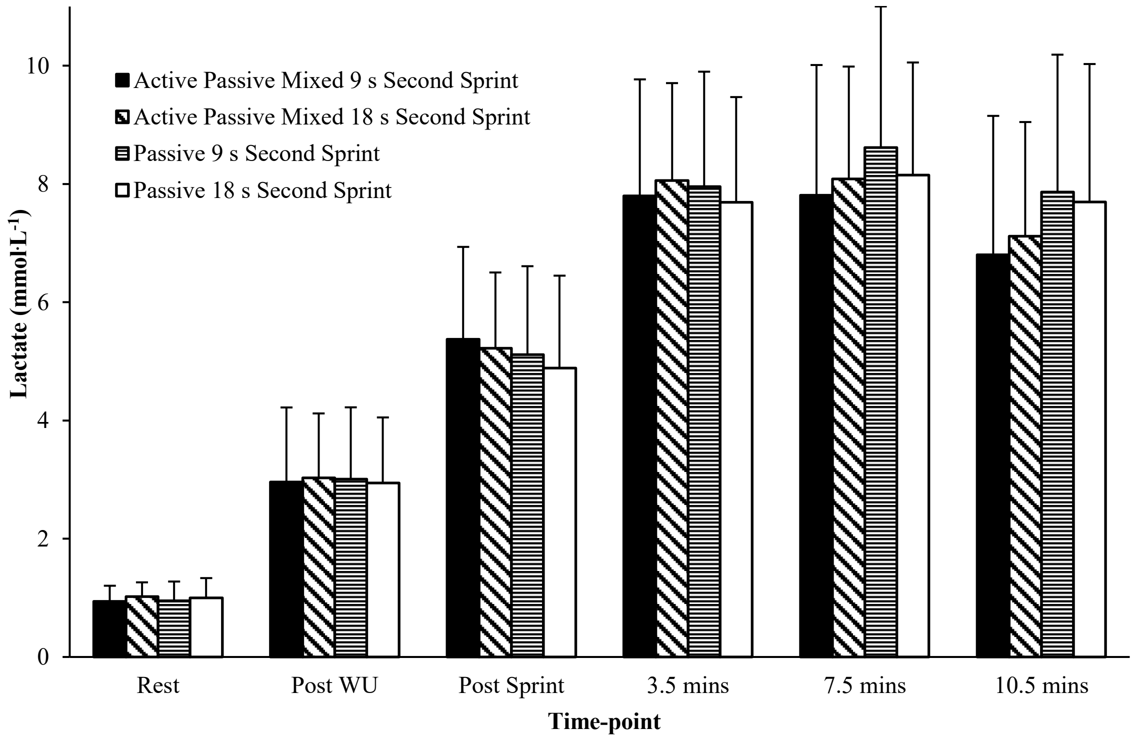

Figure 5 Blood lactate concentration at rest, after the warm-up (WU), immediately after the sprint, and following 3.5, 7.5, and 10.5 minutes of recovery, under four testing conditions. The recovery activity was either passive or a mixture of active and passive. The first sprint was always 18 s. The second sprint was either 9 s or 18 s. Bars represent the mean and error bars the standard deviation.

Preparedness to Sprint

A significant main effect ($F_{(1,23)} = 6.927$, $p = 0.015$, $\eta_p^2 = 0.157$) of sprint number was found for preparedness to sprint (see Figure 6), with the participants feeling better prepared for the second sprint. All other comparisons were not significant.

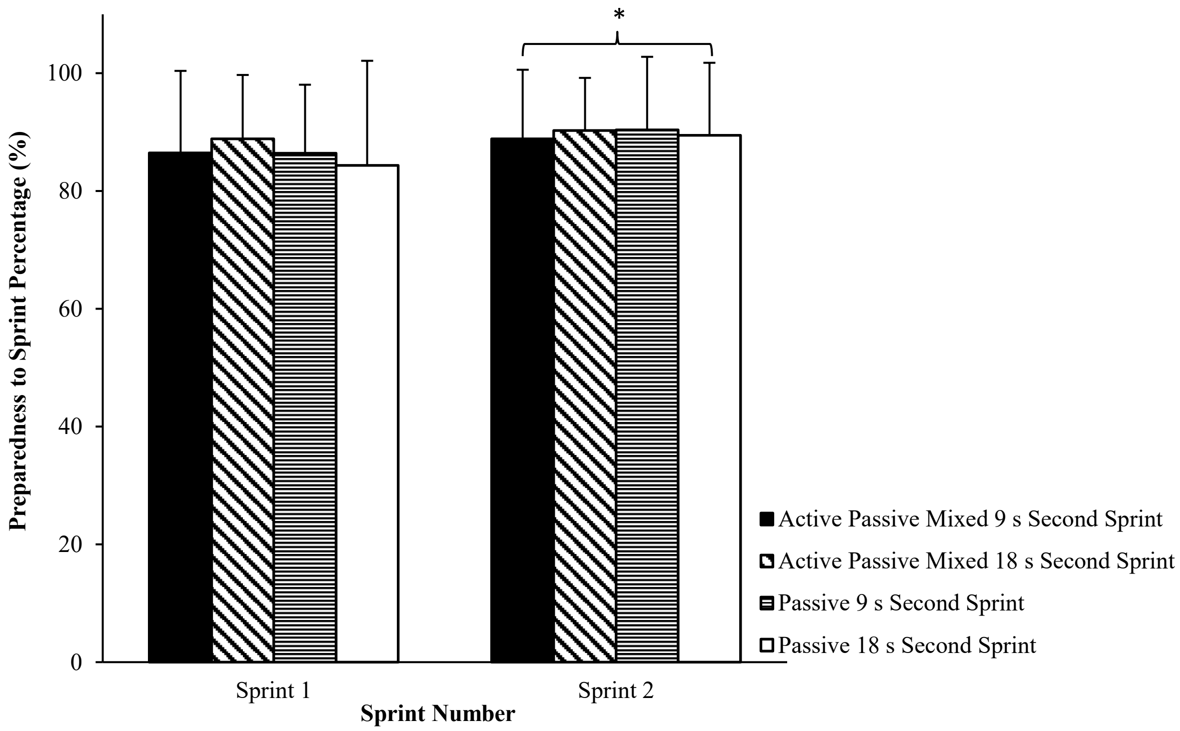

Figure 6 Rating of how prepared the participants were to sprint, measured just prior to two sprints performed 12 minutes apart. The recovery activity was either passive or a mixture of active and passive. The first sprint was always 18 s. The second sprint was either 9 s or 18 s. Bars represent the mean and error bars the standard deviation. *denotes a significant main effect ($p < 0.05$) of sprint number.

Perceptions of Recovery

Ratings of perceptions of recovery are displayed in Figure 7. The parameters of the modelled response are displayed in Table 2. The time constant did not differ significantly ($F_{(3,69)} = 0.689$, $p = 0.562$, $\eta_p^2 = 0.029$) between conditions.

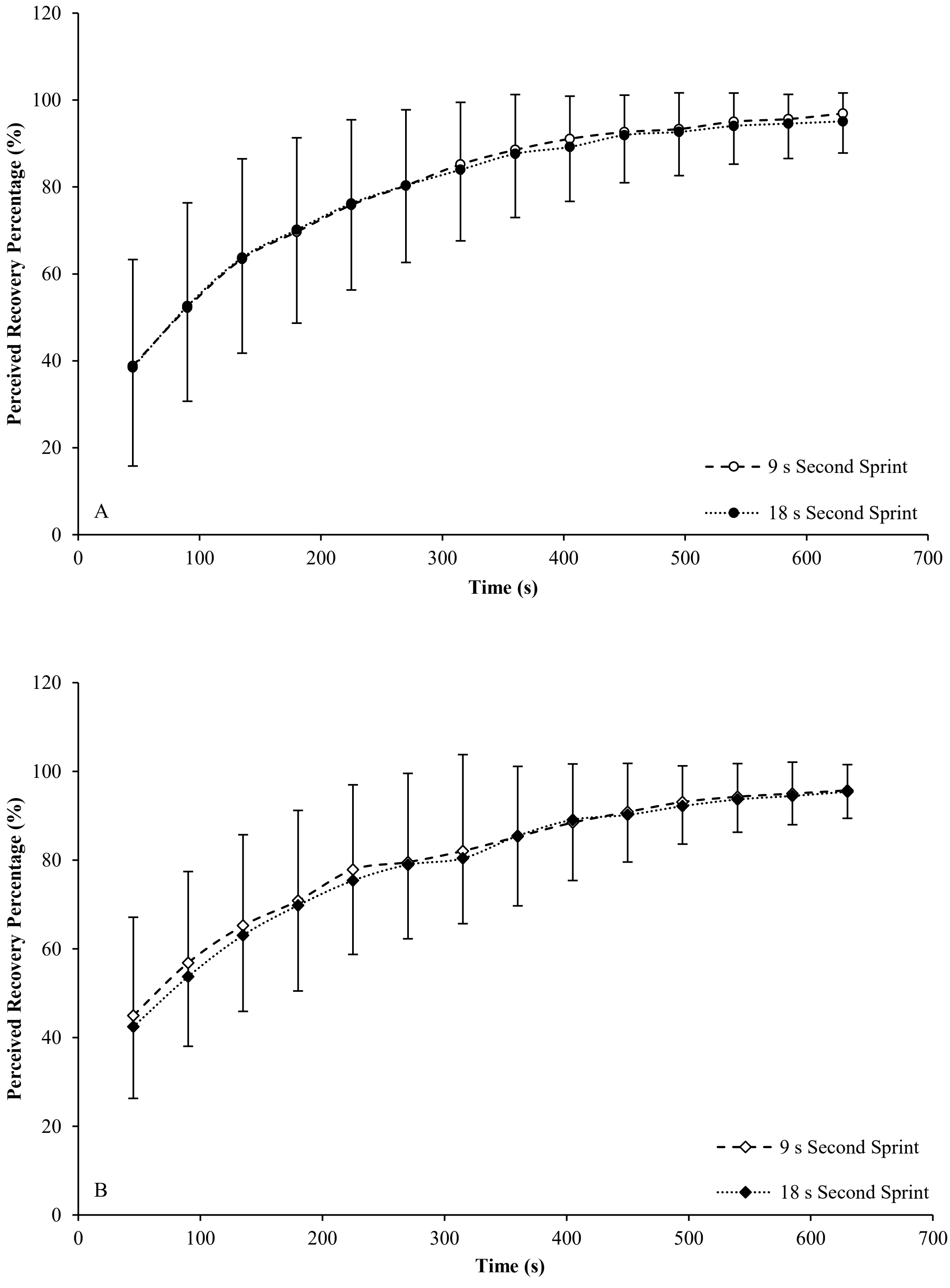

Figure 7 Perceptions of recovery following an 18 s sprint. The recovery activity was either passive (A) or a mixture of active and passive (B). The first sprint was always 18 s. The second sprint was either 9 s or 18 s. Points represent the mean and error bars the standard deviation.

Table 2 The time constant for perceptions of recovery following an 18 s sprint. The recovery activity was either passive or a mixture of active and passive. The first sprint was always 18 s. The second sprint was either 9 s or 18 s. Data are displayed as mean ± standard deviation.

Condition	Amplitude (%)	τ (s)
Active Passive Mixed 9 s Second Sprint	97.6 ± 5.3	127.1 ± 95.1
Active Passive Mixed 18 s Second Sprint	97.4 ± 5.9	158.9 ± 121.8
Passive 9 s Second Sprint	94.5 ± 7.4	140.5 ± 88.3
Passive 18 s Second Sprint	96.8 ± 5.2	140.4 ± 112.1

Note: τ denotes the time constant.

Sprint Performance Rating

Sprint performance rating differed significantly depending on the recovery method ($F_{(1,23)}$ = 4.300, p = 0.049, η_p^2 = 0.158) and the sprint number ($F_{(1,23)}$ = 6.313, p = 0.019, η_p^2 = 0.215), with higher ratings being found in the mixed recovery trials and following the second sprint. No other significant effects were found (see Figure 8).

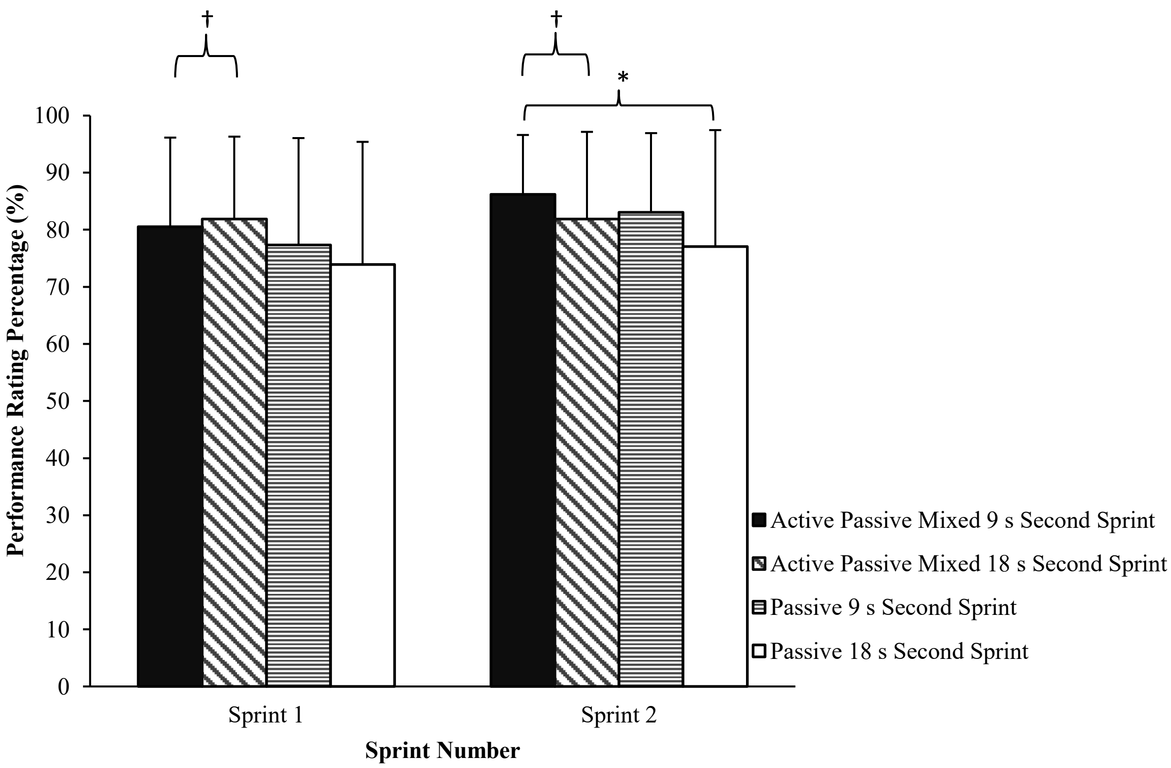

Figure 8 Performance rating following two sprints 12 minutes apart. The recovery activity was either passive or a mixture of active and passive. The first sprint was always 18 s. The second sprint was either 9 s or 18 s. *denotes a significant main effect (p < 0.05) of sprint number and †denotes a significant main effect (p < 0.05) of recovery activity.

Sprint Satisfaction

The participants generally reported that they were fairly satisfied (e.g. *'I was fairly satisfied with my sprint performance. I feel that I had a better start to the sprint than previously, but struggled to hold it for the full length of time'*), satisfied (*'Good, both efforts felt strong, on the second shorter effort I felt very strong'*), or very satisfied (*'Very happy, maximal effort and kept the leg speed up as long as I could'*) with their sprint performances. However, on eight occasions, the participants stated that they were not satisfied (*'Didn't feel great. Felt better last week'*) and on one occasion not very satisfied *('Not very'*).

Factors that Influenced Sprint Performance

When asked about what may have mostly influenced sprint performance that day, the responses focussed on physiological factors, such as good sleep (*'I had a good night's sleep and rested most of the day'*), psychological factors, such as determination (*'My personal drive to want to perform the very best I can'*) and the information provided about the second sprint duration *('Feel the biggest influence on the 9 s sprint was being told it was 9 s just beforehand – immediately makes you feel less intimidated towards the 2nd sprint and perhaps allows you to go that extra 2-3% harder knowing that there is less duration ahead'),* as well as physical factors, such as the recovery activity undertaken (*'The active recovery felt like it helped'*; *'The passive rest allowed me to fully recover after the 18 s sprint in preparation for the second sprint'*).

When specifically asked about the influence that the recovery activity may have had on second sprint performance, irrespective of the condition, the majority of participants focused on positive aspects (passive trials: '*I think it helped. I was pretty fatigued, so not doing anything seemed to be a good call'*; active/passive mixed trials: *'Moving my legs helped them to feel fresh and ready for the second sprint effort'*), although some participants stated that they would have preferred some form of active recovery to be included within the passive recovery trials *('Feel as though it may not have been the most efficient form of recovery. Ideally, would have preferred to have the legs spinning a little on the bike in-between'*), whereas when the mixed recovery protocol was undertaken, others stated that they would rather have rested passively (*'Massively influenced my perceived ability as I felt constrained by my breathing during recovery and this was compounded by my initial feeling of heavy legs before the second sprint'*).

Influence of a Financial Reward

When asked why they chose to participate in this study, participants mainly referenced aiding research (*'Contribute to research'*) or an interest in the project (*'Interested in the physiology of recovery and interested in finding out data on my own performance'*); no participants referred to the financial reward. In a similar fashion, no participants referred to the financial reward when asked about what provided the greatest influence on their approach to the sprints, with most of the responses referencing a personal challenge (*'I wanted to get the most out of myself for each effort, so my internal motivation to push myself influenced my sprint approach the most'*). When specifically asked the extent to which the offer of a financial reward affected their approach to the sprints, the majority of participants stated that the reward had little or no influence, although five participants suggested that the reward had some influence (*'The financial reward gave a slight extra motivation to push as hard as possible in the sprints, but not a significant difference as I wanted to push myself as hard as possible either way'*), and four participants suggested that the reward had a substantial influence (*'It helped me give everything in every attempt'*).

DISCUSSION

The aim of this study was to investigate the effects of recovery method, and an alteration in second sprint duration, on measures of sprint-cycling performance. The recovery of PPO altered depending on the between-sprint activity, with a significantly lower PPO being found in sprint 2 when a passive recovery was undertaken. Second sprint duration also affected the recovery of PPO, as well as MPO_9, although *post hoc* tests were unable to identify where those differences occurred. Blood lactate concentration differed between the conditions over time. However, *post hoc* analyses again did not reveal any significant differences between the conditions at the individual time-points. The participants felt better prepared for the second sprint than the first and rated their second sprint performance higher. Recovery method was also found to affect ratings of sprint performance, as well as MPO_9 and MPO_{18}, although interactions were not found with sprint number. Mixed views were expressed regarding the perceived benefits of the recovery activity undertaken, with the majority of participants focusing on positive elements, regardless of the condition. The time constant for perceptions of recovery did not differ between conditions and the offer of a financial reward did not appear to provide a major motivational factor for study participation or how the participants approached each sprint.

The outcome of an improvement in the restoration of PPO following a mixture of active and passive recovery, but with no significant difference in MPO over either 9 s or 18 s, differed to the finding that an active recovery did not affect PPO restoration, but improved the recovery of MPO over 6 s, 10 s, and 30 s, during a 30 s cycling sprint (Bogdanis et al., 1996b). Methodological differences included: the sample size; the duration of the sprints; the time separating sprints; the type of start to the sprint; the resistive load; the use of a harness to limit movement; and the intensity and format of the recovery activity. The sample size used in the current study was greater, which should improve statistical power. The type of start was consistent with previous sprint cycling research (Billaut & Basset, 2007; Dale et al., 2022) and was used to provide experimental control, although a rolling start would provide greater ecological validity when considering race conditions in the Match Sprint. The intensity and sequence of the recovery activity, as well as the time between sprints, were designed to reflect a scenario that could occur within a competition. However, when the time between two cycling sprints was very brief (15 s), a passive recovery was found to result in a significantly higher PPO and MPO than an active recovery (Dupont et al., 2007). It is, therefore, possible that the recovery time-course of PPO and MPO is affected differently by performing either an active or a passive recovery. Comparing active and passive recovery conditions at several time-points over a 12-minute period would help to clarify this suggestion.

With regards to lactate concentration, an active recovery has frequently been shown to enhance lactate clearance (Devlin et al., 2014; Kirkpatrick & Burrus, 2020; McLellan & Skinner, 1982; Menzies et al., 2010). A condition × time interaction was found for lactate concentration in the current study. The inability of *post hoc* tests to identify the location of the interaction could be because the 12-minute recovery duration was too short; especially considering that some of that recovery time was passive. The lack of an effect of an active recovery on post-exercise lactate concentration has previously been reported when the time between efforts was either four (Bogdanis et al., 1996b) or five minutes (Dorado et al., 2004). It is also possible that the rate of lactate clearance out of the muscle may have been enhanced, but that the rate of appearance in the blood increased in parallel with the rate of disappearance (Bogdanis et al., 1996b). From a participant perception perspective, in the post-trial questionnaire, some participants did indicate that an active recovery was preferable to a passive recovery, although others suggested the opposite. In fact, in general, the participants tended to focus on positive aspects of the recovery method used that day. Allowing the participants to freely select their recovery activity, would have added insight into individual preferences, as well as facilitating the ability to compare how individual preferences affect repeated-sprint performance.

A direct question about whether the participants perceived that the information about the duration of the second sprint affected their performance was not asked in the post-trial questionnaire. Nonetheless, when responding to what had mostly influenced their sprint performances that day, on five occasions the participants stated that being informed that the second sprint was shorter, motivated them just prior to the sprint. A sprint duration × sprint number interaction was found for both PPO and MPO_9, although as follow-up tests did not identify the cause of this effect, it cannot be concluded that an increase in potential motivation was elicited. When asked about what had mostly influenced their approach to the sprints in the end-of-study questionnaire, the participants frequently cited an intrinsic motivational factor, namely, a personal challenge, whereas the offer of a financial reward appeared to have little or no influence on the approach taken to the sprints by the majority of participants. Rewards have been shown to improve exercise performance during a hand-grip task (Shi et al., 2021), although cycling time-trials over shorter (1.5 km and 4 km) or longer distances (20 km) were not affected by a financial incentive (Hulleman et al., 2007; Skorski et al., 2017). The effectiveness of a particular type of motivational strategy should not, therefore, be assumed.

An additional consideration with the findings in the current study, relates to the main effects that were found for sprint number and recovery method. An overall improvement in performance during the mixed recovery trials should not be interpreted to suggest that the between-sprint activity improved performance recovery. Only the existence of an interaction effect would suggest this outcome. Even though control measures were in place, it is possible that variations in first sprint performance could have contributed to the main effect that was found. The overall significant reduction in sprint 2 performance for PPO, MPO_9, and MPO_{18} did, however, appear to contradict the perceptions reported by the participants. The participants rated their preparedness to sprint higher before the second sprint and then rated their second sprint performance as being better. The enhanced rating of how prepared the participants felt they were to sprint prior to the second sprint could be indicative of a lack of preparation for the first sprint. The warm-up protocol used was based on guidelines that have been provided for an 18 s sprint cycling test, but this may not have been optimal. Between-sprint measurements of perceptions of recovery could also have affected the markings taken before and after the second sprint. The time constant for perceptions of recovery did not differ between trials, with the mean values indicating that the participants perceived that they were fully recovered, or at least close to being fully recovered, within the recorded time-period. As the final measurement would have been taken close to when the second sprint scales were completed, it is possible that the recent markings could have affected the subsequent ratings.

Some final cautionary notes must also be made. First, the current findings can only be applied to strength-trained males. Strength-trained males were specifically recruited due to importance of resistance training for sprint cyclists (Parsons, 2010) and the higher power outputs that are typically found in this cohort (Pazin et al., 2011), although even greater power outputs have been reported in elite sprint cyclists (Kordi et al., 2020). A larger sample size would also have improved statistical power. The sample size used in the current study was in-line with (Kirkpatrick & Burrus, 2020) or greater than previous research (Billaut et al., 2011; Bogdanis et al., 1996b; Dale et al., 2022; de Jong et al., 2015; Glaister et al., 2019; Wittekind et al., 2011). Resource constraints were also considered when the study was designed. Resource constraints are omnipresent and often play an understated, but substantial role in the construction of research projects (Lakens, 2022). Data interpretation was also only conducted using traditional significance testing. This method of data interpretation has been criticised, with the suggestion that it is often used by researchers as it provides comfort by offering pseudo-objectivity (Ellis, 2010). The classification and interpretation of effect sizes as simply being small, medium, or large, may also not be ideal, as small effects can be very meaningful in sport (Ellis, 2010). Therefore, more still needs to be done to formulate a systematic approach to the interpretation of effect sizes.

In conclusion, when considering the shortest recovery periods that occur in the Match Sprint competition, there was evidence to suggest that the current practice undertaken by sprint cyclists could aid with the recovery of PPO, although the effects on overall performance were not apparent. Being informed that the second sprint duration was shorter provided a positive feeling for some participants and a change in performance recovery was found. However, for both PPO and MPO_9, the cause of the interaction was not established. Lactate concentration differed between conditions over time, although follow up tests did not identify any between condition differences at the individual time-points. It is possible that time off the bike may have limited lactate clearance. In contrast to the performance findings, the participants perceived that they were better prepared to sprint prior to their second sprint and that they performed better during the second sprint. When using VAS, the possible influence of previous markings may need to be considered. Finally, a financial reward did not appear to influence the approach that the majority of participants took to the sprints. The effectiveness of motivational strategies should be evaluated, not assumed.

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