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RESEARCH ARTICLE

Sleep restriction between consecutive days of exercise impairs sprint and endurance cycling performance

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Summary

The study aim was to determine the effect of sleep restriction (3 h) between consecutive days of exercise on sprint and endurance cycling performance, wellness, and mood. A total of 10 well-trained males performed 2 consecutive-day trials separated by a normal night sleep (control [CONT]; mean [SD] sleep duration 3.0 [0.2] h) or sleep restriction (RES; mean [SD] sleep duration 3.0 [0.2] h). Experimental trials included a 90-min fixed-paced cycling bout and the respective sleep conditions on Day 1, followed by two 6-s peak power (6-s PP) tests, a 4- and 20-min time trial (TT) on Day 2. Profile of Mood States (POMS) and wellness questionnaires were recorded on Day 1 and Day 2. Blood lactate and glucose, heart rate (HR), and rating of perceived exertion were recorded throughout Day 2. Power output (PO) was significantly reduced for RES in the 6-s PP trial (mean [SD] 1159 [127] W for RES versus 1250 [186] W for CONT; $p = 0.04$) and mean PO during the 20-min TT (mean [SD] 237 [59] W for RES versus 255 [58] W for CONT; $p = 0.03$). There were no differences for HR, lactate and glucose, or POMS between CONT and RES in all experimental trials ($p = 0.05$–0.89). Participants reported a reduction in overall wellness prior to exercise on Day 2 following RES (mean [SD] 14.5 [1.6] au) compared to CONT (mean [SD] 16 [3.0] au; $p = 0.034$). Sleep restriction and the associated reductions in wellness, reduce cycling performance during consecutive days of exercise in a range of cycling tests that are relevant to both track and road cyclists.

KEYWORDS
actigraphy, road cycling, sleep loss, track cycling

1 | INTRODUCTION

It is not uncommon for sub-elite and elite cyclists to compete in track events that require performing multiple times a day, or at least on consecutive days, such as the Olympic Games and World Championships (Richard & Koehle, 2019). Additionally, road cyclists are also subjected to consecutive days of prolonged exercise during National Road Series events in Australia and at elite-standings tours, such as the Tour Down Under and Tour de France. Due to the physiological, physical, and psychological perturbations associated with training in preparation for these types of events (Berger et al., 1999) and the competitions/events themselves (Lucía et al., 2001), there may be an

increased need for effective recovery strategies (Jeukendrup et al., 2000). As such, in more recent times, sleep has been highlighted as one of the most important recovery modalities between consecutive days of power and endurance exercise due to its physiological and psychological restorative effects (Walsh et al., 2021).

Sleep restriction between consecutive days of exercise is a common occurrence for cyclists during training and competition (Erlacher et al., 2011; Lastella et al., 2015) due to a host of reasons, including delayed onset of muscle soreness, exercise time-of-day, time-consuming recovery interventions on the preceding day, and feelings of nervousness and anxiousness about the upcoming competition (Juliff et al., 2015). Athletes experiencing sleep restriction during intended recovery periods may lead to alterations in neuroendocrine function such as circadian hormone secretion and increases in metabolic costs and energy expenditure (Jung et al., 2011). Previous literature has further shown that endurance exercise undertaken following total sleep deprivation results in augmented pacing strategies (Skein et al., 2011) including distance covered (Oliver et al., 2009). Conversely, findings observed in power-based performance tend to be less consistent. For example, 36 h of total sleep deprivation was shown to reduce peak and mean power during a 30-s Wingate test (Souissi et al., 2003); however, ~28 h total sleep deprivation had no effect on anaerobic power during the same Wingate test when compared to a normal night's sleep (Taheri & Arabameri, 2012). Conflicting results and the range of sleep and exercise protocols indicate that more research may be needed to understand the mechanisms as to why sleep restriction may affect exercise performance of varying intensities and durations, utilising a consistent sample group.

In addition to physiological mechanisms underpinning performance decrements following sleep loss, recent research has observed strong correlations between sleep restriction and increased negative mood states among athletic populations (Fullagar et al., 2015). These mood outcomes have been further shown to impact the desire and/or motivation of athletes to optimally perform during training and competition. Thus, mood-state monitoring is pertinent, in conjunction with physiological monitoring, when assessing exercise performance during various sleep protocols (Benjamin et al., 2020; Bolin, 2019). A further consideration during implementation of sleep-based protocols, is the inability to blind participants of the intervention, thus creating a potential pre-conceived assumption of their likely performance outcomes. This may be particularly pertinent in exercise protocols that are self-paced and sufficient duration in which conscious pacing strategies may be implemented.

Therefore, the aim of this study was to determine the effect sleep quantity (8 versus 3 h) between consecutive days of exercise has on self-paced cycling performance, wellness, and mood states. It was hypothesised that sleep restriction to ~3 h of sleep between consecutive days of exercise would significantly reduce mean power output (PO) during the endurance cycling tests (4- and 20-min time trials [TTs]), have a minimal effect on anaerobic cycling performance (6-s peak power [6-s PP] test), and mood states and feelings of wellness would be decreased following sleep deprivation compared to control.

2 | METHODS

2.1 | Participants

A total of 10 male well-trained track-endurance and road cyclists (four to five ≥45 min training sessions/week) (De Pauw et al., 2013) were recruited to participate in the study. The mean ± standard deviation (SD) characteristics were, age 29.9 (10.7) years, mass 78.4 (7.8) kg, and height 1.80 (0.09) m. Any persons with injuries, other physical health issues, known sleep conditions, or medication that may affect sleep were excluded from the study. All participants completed the Epworth Sleepiness Scale and were questioned about their sleeping patterns prior to initial testing (Johns, 1992). Participants were informed of the requirements and demands of the study and written informed consent was obtained prior to the commencement of testing. This study was approved by the Institutional Human Research Ethics Committee prior to data collection.

2.2 | Overview

Prior to the experimental trials, participants were required to provide 10 nights of baseline actigraphy sleep data by wearing an Actiwatch (Actiwatch 2, Philips Respironics, Murrysville, PA, USA) on their right wrist. During the actigraphy, participants also completed a sleep diary, recording time-in-bed, sleep time and wake times, and perceived sleep quality. Actigraphy monitors were also worn, and diaries completed throughout the experimental trials to ensure compliance with the sleep protocols.

Prior to testing participants completed a comprehensive familiarisation session to ensure they were accustomed with testing protocol, procedures, and equipment, then completed two experimental trials separated by at least 1 week. Each trial included 2 consecutive days of exercise with manipulation of sleep quantity in between. Day 1 consisted of a standardised 90-min fixed-paced cycling protocol completed in the afternoon and was designed to mimic the substrate depletion and metabolic accumulation that would occur during a typical training or competition day. On Day 2, participants commenced exercise at 8:30 a.m. and completed a 30-min fixed-paced cycling protocol (warm-up simulation) followed by a 30-min recovery and the experimental testing protocol including two 6-s PP trials, 4- and 20-min TTs, with a standardised low-intensity active recovery between each trial.

The sleep conditions were allocated in a counter-balanced, semi-randomised fashion, including a control (CONT) sleep, which was considered a normal night sleep, comparable with baseline data. This condition included a bedtime of 10:00 p.m. and awakening at 6:00 a.m. the following morning. The sleep restriction condition (RES) included remaining awake until 3:00 a.m. and woken at 6:00 a.m. for a total 3 h sleep duration. All testing and sleeping arrangements were provided by the research team and were consistent between conditions, which included participants residing in a bed in their own room.

Participants abstained from caffeine, alcohol, and strenuous exercise for 24 h before and throughout the experimental trials. All food and fluid during the trials were provided by the research team and standardised with a carbohydrate intake of 8 g/kg body weight (bw) and protein intake was 1.2–1.5 g/kg bw. The timing of post-exercise and volume of food on Day 1 were standardised between conditions; however, time allocated to consume snacks between dinner and bedtime during the RES condition was extended compared to the CONT condition, due to the adjustment in the time participants were kept awake. Participants were supervised and remained sedentary between finishing exercise on Day 1 and bedtime for both conditions. On Day 2, participants were provided a standardised breakfast between 6:00–6:45 a.m. and provided 500 mL of water during the 90 min cycling effort on Day 1, 200 mL during the 30 min effort on Day 2, and another 200 mL during the recovery between fixed-paced and 6-s PP protocol.

2.3 | Exercise protocol

2.3.1 | Fixed-paced cycling protocol (Day 1 and Day 2)

Upon arrival on Day 1, participants commenced with a standardised 5-min self-paced warm-up before beginning a 90-min cycling protocol at 90 revolutions/min at 60% maximal heart rate (MHR) on a cycle ergometer (Wattbike Pro, Nottingham, UK). Fan resistance was altered in the warm-up and initial 5 min of the protocol to ensure participants were within the MHR range (± 10 beats/min) and the cycle ergometer resistance identical between both experimental trials. Every 12 min, fan resistance was increased by 2 for 3 min per interval to replicate a hill climb, peloton chase, or interval training session with increased resistance increasing HR to 75%–90% MHR. The inclusion of this protocol was designed to simulate a similar energy expenditure to that of a track or road training session that would occur over consecutive days. Prior to the experimental trial on Day 2, participants completed a 5-min warm-up before a 30-min cycling protocol at the same resistance and cadence as Day 1 to maintain 60% MHR, with no resistance alterations.

2.3.2 | The 6-s PP protocol

Participants completed two 6-s PP trials on a cycle ergometer with peak and mean PO recorded. Participants chose their preferred resistance from the familiarisation session and this resistance remained consistent between sprints and conditions (fan resistance range: 7–10). Participants commenced from a stationary start with dominate foot forward with crank position at 45° forward of top dead centre. Participants completed the 6-s PP test aiming to achieve the highest PO possible and were consistently given verbal encouragement during the sprints to ensure maximal effort and were privy to performance and physiological data during the test. A 1-min recovery period was allocated between each 6-s PP trial.

2.3.3 | The 4-min TT

Following the 6-s PP trials, a 5-min recovery was allocated before the ensuing 4-min TT. During the recovery period participants completed active recovery with cycling at the lowest resistance (fan resistance 1). Participants were able to choose their own pre-determined resistance for the 4-min TT and was standardised between conditions (fan resistance range: 3–5). The TT commenced from a stationary start, identical to the 6-s PP test, with instructions to cover as much distance as possible in the 4 min. Participants were given consistent verbal encouragement during the TT to ensure maximal effort was given and were privy to performance and physiological data during the test.

2.3.4 | The 20-min TT

The 20-min TT was completed following a 10-min active recovery following the 4-min TT on fan resistance 1. Similar to the two previous protocols the resistance on the cycle ergometer was pre-determined by the participant (fan resistance range: 2–4) and was standardised between conditions. The 20-min TT was self-paced, providing all performance and physiological data in real time and participants were instructed to cycle the furthest distance possible in the time allocated.

2.4 | Performance, physiology and perceptual measures

Sleep quality and quality were assessed using an Actiwatch2 worn on the right wrist at all times and sleep diaries for 10 consecutive nights. Data were recorded continuously in 30-s epochs and were downloaded to accompanied software (Actilife 5; Philips Respironics). With the sleep diaries, actigraphy data identified non-wearing times, bed and wake times, calculated sleep times, sleep latency (number of minutes between start and rest and first epoch of scored sleep), sleep efficiency (number of sleep minutes divided by the total number of minutes the participant was in bed), total time in bed (total number of minutes from time in bed to time out of bed), total sleep time (TST; total number of minutes scored as 'asleep'), wake after sleep onset (WASO; the total number of minutes the participant was awake after sleep onset occurred), number of awakenings (the number of awakenings episodes), average awakening (the average length of time, in minutes during each awakening episode), and perceived sleep quality using a 1–5 Likert scale compared to a normal night sleep (1: poor – 5: excellent).

On arrival at each experimental trial, body mass was recorded on a calibrated set of scales. Urine specific gravity (USG) was also recorded using a digital refractometer from a mid-stream urine sample provided on Day 2 to ensure participants did not commence exercise

TABLE 1 Mean ± SD power output (PO), cadence for control (CONT) and sleep restriction (RES) conditions on Day 2

Variable	CONT, mean (SD)	RES, mean (SD)
6-s PP		
PO, W	1250 (187)	1159 (127)[a]
4-min TT		
PO, W	337 (75)	316 (77)
Cadence, revolutions/min	103 (10)	103 (10)
20-min TT		
PO, W	254 (58)	237 (59)[a]
Cadence, revolutions/min	96 (8)	97 (10)

[a]Significant difference between CONT and RES condition ($p = 0.034–0.037$).
Abbreviations: 4-min TT, 4-min time trial; 20-min TT, 20-min time trial; 6-s PP, 6-s peak power test; PO, power output; TT, time trial.

in a dehydrated state (threshold: 1.020; Refractometer 503, Now. Nippon Optical, Works Co, Tokyo, Japan). The HR was recorded before and after the 6-s PP trial and each minute throughout the time trials with a HR monitor and instantaneous feedback via Bluetooth to the Polar Team Sport 2 software (Polar Team System, Polar Electro Oy, Kempele, Finland). A capillary blood sample was collected via a small incision of the fingertip for assessment of lactate (Lactate Pro, Arkray KDK, Kyoto, Japan) and glucose (Accu Check, Roche Diagnostics, Abbott Park, IL, USA) before the 30-min fixed-paced protocol, before the 6-s PP trial and after the 20-min TT.

Performance measures recorded were PO and cadence (revolutions/min) during the TTs. The peak PO during the 6-s PP was recorded as the highest PO for each effort, while mean PO was determined as the average of the two 6 s efforts. PO and cadence were manually recorded every minute during the 4- and 20-min TTs, with mean PO determined as the average from these respective time points.

Rating of perceived exertion (RPE) was recorded after each 6-s PP trial using Borg's 6–20 point scale (Borg, 1982). During the 4- and 20-min TTs, RPE was recorded every minute and 2 min, respectively. A wellness questionnaire was completed before exercise on Day 1 and before and after exercise on Day 2 for the assessment of fatigue, sleepiness, mood, muscle soreness and stress levels using a 1–5 Likert scale (Gallo et al., 2016). Furthermore, a modified Profile of Mood States (POMS) questionnaire with the assessment of tense, angry, depressed, confused, fatigue and vigour completed before exercise on both Day 1 and 2, and after exercise on Day 2.

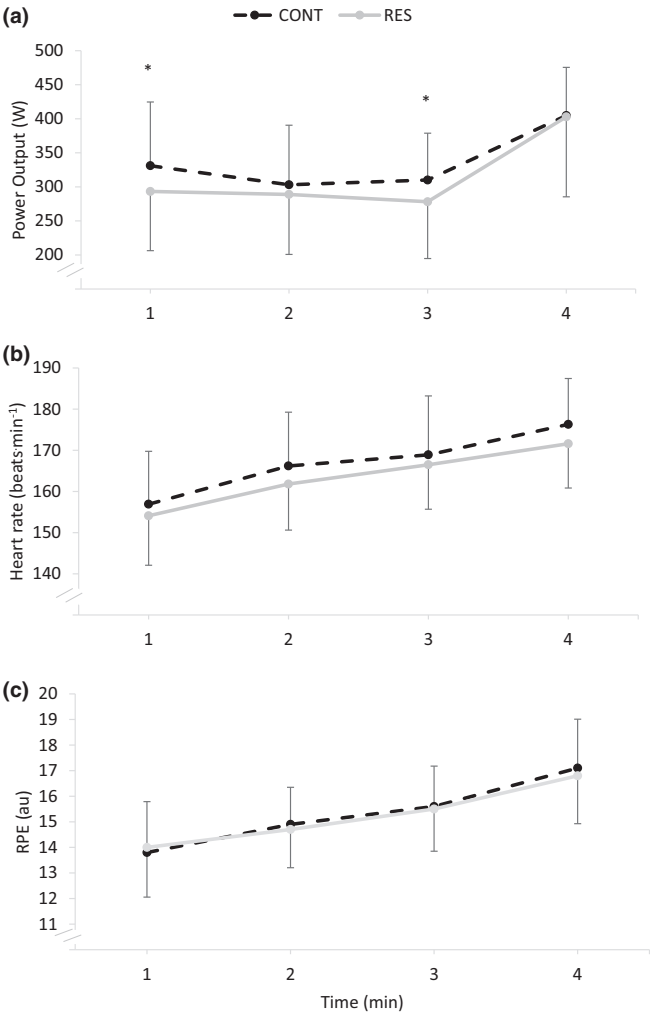

FIGURE 1 Mean ± SD (a) power output, (b) heart rate (HR), and (c) rating of perceived exertion (RPE) at 1-min intervals during the 4-min time trial (TT) between control (CONT) and sleep restriction (RES) conditions

2.5 | Statistical analysis

Data are reported as mean (± SD). A Shapiro–Wilk test was initially completed and indicated all data were within a normal distribution. Mauchly's test was completed and identified the variances of the differences between the levels (time, condition, time × condition) of the within-subjects factor are equal. Performance, physiological, perceptual and sleep data were analysed using a repeated measures (time, condition, and time × condition interaction) analysis of variance (ANOVA) with a Bonferroni correction. Tukey's post hoc analysis was used to determine where significant differences were present. Significance was set at $p = 0.05$ with F statistic and partial eta squared (η^2) data reported. All data analysis was completed using the Statistical Package for Social Sciences (SPSS; IBM, version 27.0).

3 | RESULTS

3.1 | Performance

There was a significant effect of condition with mean PO across both sprints being higher during CONT compared to RES ($p = 0.037$;

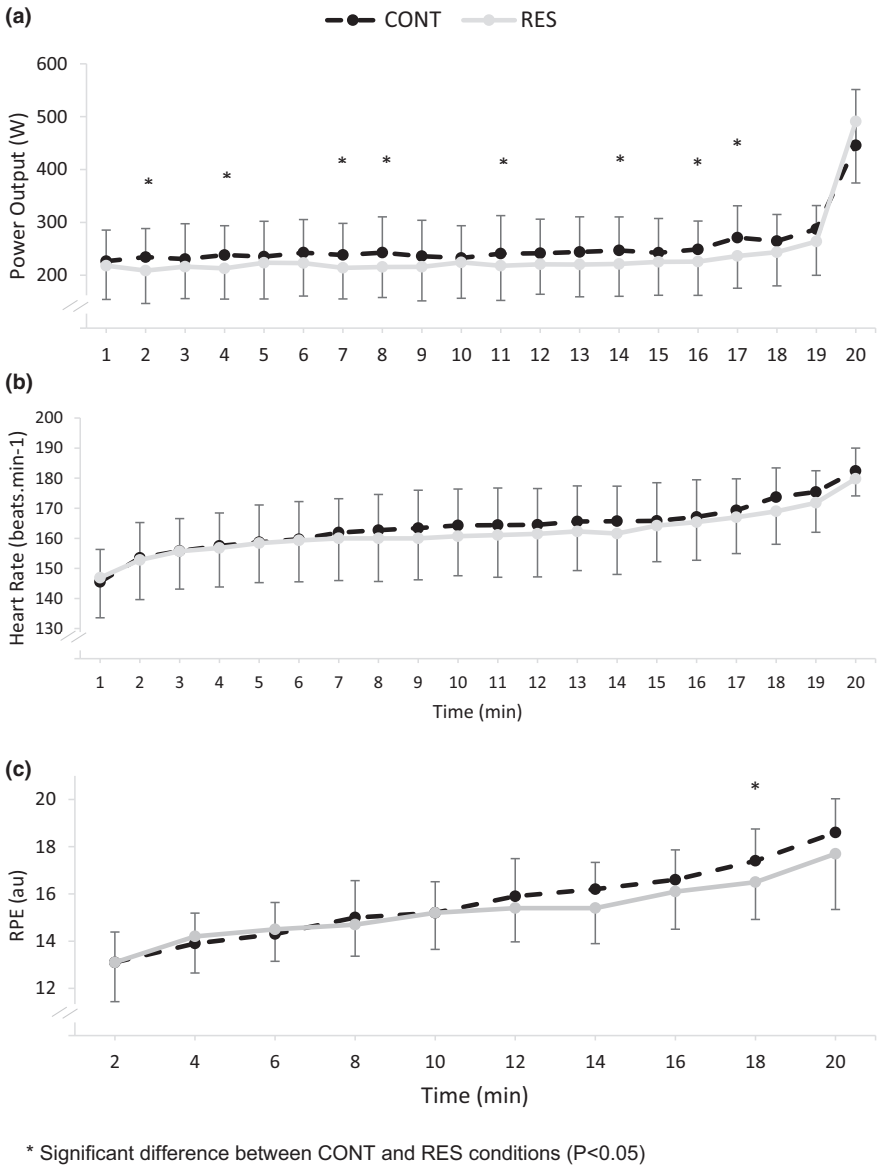

FIGURE 2 Mean ± SD (a) power output, (b) heart rate (HR), and (c) rating of perceived exertion (RPE) at 1-min intervals during the 20-min time trial (TT) between control (CONT) and sleep restriction (RES) conditions

$F = 5.943$; Table 1), and a significant effect of time in Sprint 1 where PO was higher in CONT (mean [SD] 1241 [201] W) compared to RES (mean [SD] 1120 [164] W; $p = 0.037$). There was no difference for Sprint 2 between the conditions, at a mean (SD) of 1259 (174) W for CONT and 1198 (145) W for RES ($p = 0.193$; $F = 1.983$).

There were no differences between conditions for mean PO during the 4-min TT ($p = 0.135$; $F = 2.703$; $\eta^2 = 0.231$; Table 1). However, PO was higher in the CONT at 1 and 3 min ($p = 0.018$–0.049; $F = 11.668$; $\eta^2 = 0.536$; Figure 1a) compared to RES, while no differences were recorded at 2 or 4 min ($p = 0.063$–0.096; $F = 11.668$; $\eta^2 = 0.536$ Figure 1a).

The mean PO was significantly increased in the 20-min TT in CONT compared to RES ($p = 0.034$; $F = 6.214$; $\eta^2 = 0.408$ Table 1). Furthermore, as shown in Figure 2a, an increase in PO was present in CONT compared to RES at multiple time points during the trial ($p = 0.004$–0.04; $F = 2.68$; $\eta^2 = 0.408$).

3.2 | Sleep

There were no differences in TST between the baseline (mean [SD] 385 [63] min) and the CONT condition (mean [SD] 434 [28] min; $p = 0.08$; $F = 0.07$; $\eta^2 = 3.86$), while TST was reduced during RES (mean [SD] 163 [13] min) compared to baseline ($p = 0.001$) and CONT ($p = 0.01$; $F = 2.40$; $\eta^2 = 0.023$).

There were no differences in sleep latency between the baseline (mean [SD] 35 [9] min) and CONT (mean [SD] 25 [10] min; $p = 0.07$; $F = 1.1$; $\eta^2 = 0.06$); however, a reduction in latency was observed for RES (mean [SD] 14 [5] min) compared to baseline ($p = 0.001$) and CONT ($p = 0.014$). Sleep efficiency was not significantly different between conditions (mean [SD] 88%[12%] for CONT and 90%[7%] for RES; $p > 0.05$) or compared to baseline (mean [SD] 82%[7]%; $p = 0.06$–0.90; $F = 4.80$; $\eta^2 = 6.33$).

There were no differences in WASO between baseline (mean [SD] 27.9 [8.6] min) and CONT (mean [SD] 21.7 [11.2] min; $p = 0.09$;

TABLE 2 Mean ± SD capillary blood glucose and lactate concentrations before the fixed-paced cycling on Day 1, before the experimental protocol and immediately after the experimental protocol on Day 2, for control (CONT) and sleep restriction (RES) conditions.

	CONT, mean (SD)	RES, mean (SD)
Glucose, mmol/L		
Before Exercise (Day 1)	5.2 (0.5)	5.4 (0.8)
Before Protocol (Day 2)	4.8 (0.7)	4.8 (0.6)
After Protocol (Day 2)	4.3 (0.9)	4.9 (0.6)
Lactate, mmol/L		
Before Exercise (Day 1)	2.8 (0.7)	2.7 (1.8)
Before Protocol (Day 2)	2.9 (1.6)	3.4 (2.6)
After Protocol (Day 2)	10.6 (1.9)	10.9 (2.2)

Note: No significant differences between conditions.

$F = 1.45$; $\eta^2 = 0.33$); however, a reduction in WASO was observed for the RES condition (mean [SD] 5.5 [8.3] min) compared to CONT ($p = 0.038$; $F = 5.23$; $\eta^2 = 0.43$). The total number of awakenings was also not different between baseline (mean [SD] 38 [12] au) and CONT (mean [SD] 27 [7] au; $p = 0.08$; $F = 3.89$; $\eta^2 = 0.13$); however, was reduced for RES (mean [SD] 7 [2] au; $p = 0.0001$; $F = 3.4$; $\eta^2 = 0.88$).

3.3 | Physiological

During the 6-s PP trial, the HR was not different between CONT (mean [SD] 142 [12] beats/min) and RES (mean [SD] 144 [8] beats/min; $p = 0.460$; $F = 0.595$; $\eta^2 = 0.062$). Similarly, during the 4-min TT no differences in HR were present between CONT (mean [SD] 167 [13] beats/min) and RES (mean [SD] 164 [11] beats/min; $p = 0.162$; $F = 2.324$; $\eta^2 = 0.205$) or at any time point during the trial ($p = 0.06$–0.08; Figure 1b). Furthermore, the HR during the 20-min TT was not different between CONT (mean [SD] 164 [11] beats/min) and RES (mean [SD] 162 [12] beats/min; $p = 0.386$; $F = 0.831$; $\eta^2 = 0.085$) and no differences were present at all time points ($p = 0.05$–0.09; Figure 2b).

As shown in Table 2, there were no differences between the CONT and RES conditions for capillary blood glucose ($p = 0.215$; $F = 1.87$; $\eta^2 = 0.319$) or lactate ($p = 0.536$; $F = 0.026$; $\eta^2 = 0.03$) before or after cycling trials. There was also no difference for USG for CONT (mean [SD] 1.018 [0.007]) and RES (mean [SD] 1.008 [0.004]; $p = 0.06$; $F = 0.059$; $\eta^2 = 0.06$). Furthermore, there were no differences for pre-exercise mass between CONT (mean [SD] 82.4 [10.8] kg) and RES on Day 2 (82.2 [10.5] kg; $p = 0.12$; $F = 0.078$; $\eta^2 = 0.12$).

3.4 | Perception

There were no differences for RPE during the 6-s PP trial between CONT (mean [SD] 15 [2] au) and RES (mean [SD] 14 [1] au; $p = 0.564$; $F = 0.358$; $\eta^2 = 0.038$). Furthermore, 4-min TT mean RPE or at individual time points were not different between CONT (mean [SD] 15 [2] au) and RES (mean [SD] 15 [2] au) conditions ($p = 0.784$, $F = 0.08$; $\eta^2 = 0.009$; Figure 2c). As shown in Figure 2c, RPE during the 20-min TT was increased at 18 min for CONT compared to RES ($p = 0.04$; $F = 3.58$; $\eta^2 = 0.038$), while no differences were present at any other time points throughout the 20-min TT ($p = 0.420$; $F = 0.715$; $\eta^2 = 0.074$).

There were no differences between conditions for tense, angry, depressed, confused, fatigue and vigour within the modified POMS questionnaire, before exercise on Day 1 and before and after exercise on Day 2 ($p = 0.071$; $F = 4.025$; $\eta^2 = 0.318$; Table 3). Total wellness score (sum of fatigue, sleep quality, general muscle soreness, stress and mood scores) was reduced before exercise for RES on Day 2 compared to CONT ($p = 0.034$; $F = 2.66$; $\eta^2 = 0.604$; Table 4), with no differences between conditions for all individual wellness questions ($p = 0.141$; $F = 0.206$; $\eta^2 = 0.225$; Table 4).

4 | DISCUSSION

The aim of this study was to determine the effect of sleep quantity (8 versus 3 h) between consecutive days of exercise on power-based and endurance cycling performance, physiological responses, wellness, and mood states. Novel aspects of this study were the incorporation of a range of cycling events with the same sample group, and a study design which is representative of a practical setting in which cyclists are expected to train and/or compete on consecutive days, which may have implications on performance if recovery is impaired by poor sleep (Richard & Koehle, 2019). Despite existing familiarity with the protocols, participants also completed a full familiarisation and completed the conditions in a randomised order to reduce the risk of a learning effect. The main finding from this study was that 3 h sleep restriction between consecutive days of cycling efforts reduces both sprint (6-s PP) and endurance (20-min TT) performance, with intermittent reductions during the 4-min TT, despite no substantial changes in physiological variables. However, given the self-paced nature of the protocols, data does suggest a higher HR response for a given PO following sleep restriction. While mood states were not altered by sleep restriction, total wellness was significantly reduced before exercise on Day 2, and mean RPE was similar between conditions despite the differences in mean PO.

The utilisation of a self-paced cycling protocol allowed participants to manipulate exercise intensity throughout the protocol and thus improves ecological validity to training and competition settings. Interestingly, findings from the present study indicate track-endurance and road races may be impaired by sleep restriction as indicated by a decrease in PO. In addition, the lower mean PO following sleep restriction was evident despite no differences in HR and blood parameters. Similarly, Oliver et al. (2009) highlighted reductions in distance covered during a 30-min self-paced exercise bout with no effects on physiological variables, including core temperature and HR following overnight sleep deprivation. However, Souissi et al. (2020)

TABLE 3 Mean ± SD modified Profile Of Mood States (POMS) questionnaire responses for control (CONT) and sleep restriction (RES) conditions on arrival on Day 1, before exercise and after exercise on Day 2

	Tense, mean (SD)	Angry, mean (SD)	Depressed, mean (SD)	Confused, mean (SD)	Fatigue, mean (SD)	Vigour, mean (SD)
CONT						
Day 1 Before	0.1 (0.3)	0.0 (0.0)	0.0 (0.0)	0.1 (0.3)	0.4 (0.5)	0.4 (0.7)
Day 2 Before	0.2 (0.4)	0.0 (0.0)	0.2 (0.4)	0.0 (0.0)	1 (0.9)	0.3 (0.4)
Day 2 After	0.7 (0.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.8 (1.1)	0.6 (0.7)
RES						
Day 1 Before	0.3 (0.5)	0.0 (0.0)	0.1 (0.3)	0.0 (0.0)	0.6 (0.5)	0.5 (0.7)
Day 2 Before	0.4 (0.5)	0.1 (0.3)	0.2 (0.4)	0.1 (0.3)	1.7 (0.9)	0.2 (0.4)
Day 2 After	0.4 (0.7)	0.2 (0.3)	0.0 (0.0)	0.0 (0.0)	2.1 (0.9)	0.5 (0.8)

Note: No significant differences between conditions.

TABLE 4 Mean ± SD Wellness questionnaires scores including, fatigue, sleep quality, general muscle soreness (GMS), stress and mood for control (CONT) and sleep restriction (RES) conditions on arrival on Day 1, before exercise and after exercise on Day 2

	Fatigue /5, mean (SD)	Sleep quality /5, mean (SD)	GMS /5, mean (SD)	Stress /5, mean (SD)	Mood /5, mean (SD)	Total score /25, mean (SD)
CONT						
Day 1 Before	3.2 (0.8)	4.1 (0.6)	3.2 (0.6)	3.7 (0.9)	4.1 (0.3)	18.3 (2.2)
Day 2 Before	2.6 (0.5)	3.3 (1.1)	3.1 (1.0)	3.2 (0.6)	3.8 (0.6)	16.0 (3.0)
Day 2 After	2.3 (0.7)	3.1 (0.9)	2.4 (0.8)	3.4 (1.0)	3.6 (0.5)	14.8 (2.7)
RES						
Day 1 Before	3.3 (0.8)	4.0 (0.7)	3.4 (0.8)	3.6 (0.7)	4.2 (0.4)	18.5 (2.8)
Day 2 Before	2.1 (0.3)	3.2 (1.0)	2.7 (0.5)	3.1 (0.3)	3.4 (0.5)	14.5 (1.6)[a]
Day 2 After	1.9 (0.3)	3.2 (1.0)	2.5 (0.8)	3.3 (0.8)	3.7 (0.7)	14.5 (2.4)

[a]Significant difference between CONT and RES condition ($p = 0.034$).

reported reduced 12-min self-paced running performance following 1 night partial sleep deprivation (1.5 h sleep), which included attenuated core temperature, HR, ventilation, and oxygen consumption. In addition, previous works have shown that reduced sleep via restriction and deprivation can increase cardiovascular load (Zhong et al., 2005) and reduce muscle glycogen re-synthesis (Skein et al., 2011) between consecutive days of exercise. Notwithstanding, these findings would suggest that sleep restriction of 3 h requires a downregulation of exercise intensities during endurance cycling to compensate for physiological perturbations.

Due to the nature of the interventions, it was not possible to blind participants to their respective conditions. Therefore, it may be likely that in addition to centrally-mediated regulation of physiological responses following different sleep conditions, participants may have also consciously reduced their PO when undertaking the RES condition due to preconceived notions that sleep restriction impairs performance and/or increases physiological and psychological strain (Jeukendrup et al., 2000; Skein et al., 2011). In support of the notion of conscious perceptions of unblinded sleep restriction, a possible contributor to the reduction in cycling performance was the decreased feelings of overall wellness following sleep restriction. A lack of sleep has been reported to have a direct correlation with negative moods, less motivation, and decreased feelings of wellness (Short & Louca, 2015; Van Helder & Radomski, 1989). Recently, Roberts et al. (2019) observed slower TT times following sleep restriction (reduced by 30%), with higher mood disturbance also observed. While still under considerable debate, it has also been shown that mental stress and/or fatigue is experienced, independent of physiological changes, self-paced exercise performance can reduce (Brownsberger et al., 2013), while other studies have reported no effect on cycling performance (Holgado et al., 2019; Silva-Cavalcante et al., 2018). Pain thresholds have also been shown to be compromised following sleep restriction (4 h/night) with accompanied increases in interleukin 6 (Haack et al., 2007); however, like previous works (Chase et al., 2017), general muscle soreness during the wellness questionnaire was not affected by sleep restriction. Collectively, changes in mood and overall athlete wellness following sleep restriction, in addition to the known manipulation of sleep quantity, both of which possibly contributed to the observed performance declines in the sprint and endurance domains.

While most cycling studies have focused on endurance events, implications of sleep on sprint cycling warrants further investigation. An interesting finding from the present study was the significant reduction in mean PO observed during the 6-s sprint trials, despite previous literature reporting that sleep deprivation has little to no effect on anaerobic performance (Souissi et al., 2003; Souissi

et al., 2008; Van Helder & Radomski, 1989). The majority of the previous literature surrounding this topic has focused on a full night of sleep deprivation preceding the anaerobic exercise performance the following day. A possible explanation for the reduction in 6-s sprint performance may be associated with the warm-up, 30-min cycling performed prior to the sprints. While the sub-maximal cycling may have induced some fatigue, the inclusion of the warm-up was designed to be indicative of typical practise during a track cycling competition to engage energy systems (Wittekind & Beneke, 2011), facilitate potentiation practises (Munro et al., 2017), and psychological preparation (Tomaras & MacIntosh, 2011), and therefore findings from the present study may be more applicable to athletes and coaches. Another possible explanation for the lower PO during the RES condition may be associated with fuel substrates during Day 2. Previous works have shown that despite a controlled diet, sleep deprivation blunts muscle glycogen re-synthesis during consecutive days of exercise (Skein et al., 2011) and has been suggested the alteration to substrate metabolism is multi-factorial including increased energy expenditure due to increased time awake, and potential changes in neuroendocrine regulation, including influences on ghrelin and leptin secretion, and increases in cortisol concentrations. Given this knowledge, the dependence on carbohydrates during high-intensity to maximal exercise and the 30-min cycling prior to the tests, fuel supplies may have been impaired during the sprint efforts. Furthermore, the negative feelings of wellness may have impacted the participants' performance in the 6-s PP tests similar to the endurance TTs, although future research should focus on the effects of sleep restriction, the consequences on wellness states and the effects on anaerobic performance.

5 | CONCLUSION

In conclusion, sleep restriction of 3 h/night between consecutive days of exercise, which replicates typical training and competition schedules, negatively affects cycling performance the ensuing day. In part, this may be due to a downregulation of exercise intensity to maintain similar physiological responses, reduced overall feelings of wellness, and the preconceived idea that sleep restriction will negate exercise performance. The findings suggest that not only is sleep important for exercise performance but, wellbeing, which may also influence cycling performance. Finally, it is suggested that both sprint and endurance cyclists should prioritise sleep as a key recovery strategy during training and competition preparation given the detrimental effects of sleep restriction on performance.

PRACTICAL IMPLICATIONS

- Sleep restriction has negative implications on sprint and endurance cycling performance and wellness outcomes.
- It must be a consideration of coaches and support staff that when athletes cannot be blinded to perceived negative situations (i.e., poor sleep, nutrition, travel commitments), these may have implications on performance, independent of physiological changes.
- Efforts should be made to ensure athletes attain adequate sleep when they are required to exercise on consecutive days.

AUTHOR CONTRIBUTIONS

Melissa Skein, Blake Dean were involved in the study design, data collection, analysis, and writing. Tegan Hartmann was involved in data analysis and writing. Georgia Wingfield and Penelope Larsen were involved in data collection and writing.

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CONFLICT OF INTERESTS STATEMENT

No conflicts of interest or financial support associated with this study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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