

1 **Title:** The effect of overnight sleep deprivation following competitive rugby league matches
2 on post-match physiological and perceptual recovery.

3

4 **Submission Type:** Original Investigation

5

6 **Authors:** Melissa Skein¹, Rob Duffield¹, Geoffrey M Minett^{1,2}, Alanna Snape¹, Alistair
7 Murphy¹

8

9 **Affiliation:** ¹ School of Human Movement Studies, Charles Sturt University,
10 Bathurst, NSW, Australia

11 ² School of Exercise and Nutrition Sciences, Queensland University of
12 Technology, Kelvin Grove, QLD, Australia

13 **Corresponding Author:**

14 Melissa Skein

15 School of Human Movement Studies

16 Charles Sturt University

17 Bathurst, NSW AUSTRALIA 2795

18 Email: mskein@csu.edu.au

19 Phone: +61 2 63384430

20 Fax: +61 2 63384065

21

22 **Running Head:** Recovery from rugby league match following sleep deprivation

23 **Abstract Word Count:** 250

24 **Text-Only Word Count:** 4198

25 **Number of Figures:** 2

26 **Number of Tables:** 3

27 **Keywords:** sleep loss, intermittent-sprint exercise, muscle damage, team sports

28

1 **ABSTRACT**

2 **Purpose:** This study examined the effects of overnight sleep deprivation on recovery
3 following competitive rugby league matches.

4 **Methods:** Eleven male, amateur rugby league players performed two competitive matches,
5 followed by either a normal night's sleep (~8h; CONT) or a sleep deprived night (~0h;
6 SDEP) in a randomised fashion. Testing was conducted the morning of the match, and
7 immediately post-match, 2h post and the next morning (16h post-match). Measures included
8 counter-movement jump (CMJ) distance, knee extensor maximal voluntary contraction
9 (MVC), voluntary activation (VA), venous blood creatine kinase (CK) and C-reactive protein
10 (CRP), perceived muscle soreness and a word-colour recognition cognitive function test.
11 Percent change between post- and 16h post-match was reported to determine the effect of the
12 intervention the next morning.

13 **Results:** Large effects indicated a greater post- to 16h post-match percentage decline in CMJ
14 distance following SDEP compared to CONT ($P=0.10-0.16$; $d=0.95-1.05$). Similarly, the
15 percentage decline in incongruent word-colour reaction times were increased in SDEP trials
16 ($P=0.007$; $d=1.75$). Measures of MVC did not differ between conditions ($P=0.40-0.75$;
17 $d=0.13-0.33$), though trends for larger percentage decline in VA were detected in SDEP
18 ($P=0.19$; $d=0.84$). Further, large effects indicated higher CK and CRP responses 16h post-
19 match during SDEP compared to CONT ($P=0.11-0.87$; $d=0.80-0.88$).

20 **Conclusions:** Sleep deprivation negatively affected recovery following a rugby league
21 match, specifically impairing CMJ distance and cognitive function. Practitioners should
22 promote adequate post-match sleep patterns or adjust training demands the next day to
23 accommodate the altered physical and cognitive state following sleep deprivation.

24

1 INTRODUCTION

2 Competitive rugby league matches result in high neuromuscular, physiological and
3 perceptual strain due to repeated high-intensity efforts and inter-player collisions.¹⁻²
4 Accordingly, post-match recovery can be prolonged, interrupting subsequent recovery or
5 training sessions.³ For instance, maximal voluntary contraction (MVC) torque and twitch-
6 contractile properties have been shown to be suppressed 2 h post-match.³ Further, McLellan
7 et al.⁴ reported counter-movement jump (CMJ) peak power are reduced up to 24 h post-
8 match, alongside elevated biochemical markers of stress and muscle damage. Although
9 evidence of the post-match and subsequent recovery of physiological state exists,^{3,4} limited
10 research examines the influence of post-match circumstances that potentially impair
11 recovery.

12

13 Situations resulting in disruptions to post-match recovery that are commonly experienced by
14 team sport athletes, such as rugby league players may include travel demands, unfamiliar
15 sleeping arrangements, anxiety, or social commitments; all of which are known to interrupt
16 sleep patterns.⁵⁻⁸ Sleep deprivation has been shown to negatively affect ensuing exercise
17 performance, such as walking time to exhaustion,⁹ sub-maximal strength,¹⁰ peak power
18 during a maximal cycling effort,¹¹ and distance covered in self-paced treadmill running.¹²
19 More pertinent to rugby league, Skein et al.¹³ reported a reduction in intermittent-sprint
20 performance, maximal voluntary force, muscle glycogen concentration, and an increase in
21 perceptual stress following 30 h sleep deprivation. While these studies provide insight into
22 the effects of sleep deprivation on ensuing performance, minimal research has examined the
23 effects of sleep deprivation on post-exercise recovery, particularly from ‘real-world’
24 competitive team-sport matches.

1 The mechanisms proposed to explain reduced performance following sleep deprivation are
2 unknown, though are reported to include increased cardiovascular and thermoregulatory
3 strain, alterations in hormone regulation and increased waking metabolic demands.¹⁴⁻¹⁵ It is
4 also known that sleep enhances anabolic processes and particularly when tissue damage is
5 present, the rate of healing is greater during sleep.¹⁶ Furthermore, reductions in exercise
6 performance have been attributed to increased perceptual stress, as observed from Profile of
7 Mood States (POMS) questionnaires¹⁷ or increased Rating of Perceived Exertion (RPE) for a
8 given workload.¹⁸ The array of purported mechanisms may be due to the inability to blind
9 subjects to the sleep condition resulting in a negative placebo (nocebo) effect on exercise
10 performance and cognitive function.¹⁹ Nevertheless, it appears that exercise performance and
11 cognitive function are impaired following acute sleep deprivation, though the contribution of
12 the proposed mechanisms responsible are unclear, and particularly on the post-exercise
13 recovery process.⁶

14

15 Accordingly, the current understanding of sleep deprivation and ensuing effect on recovery
16 following exercise is lacking, particularly in a competitive team sport scenario. Furthermore,
17 the effects of increased physiological and perceptual stress on performance outcomes are also
18 unclear. Therefore, this study aimed to examine the effect of sleep deprivation on next-day
19 recovery of neuromuscular, physiological and cognitive function following rugby league
20 competition. It was hypothesised that one night's sleep deprivation would negatively affect
21 post-match recovery of neuromuscular and cognitive function and increase perceptual stress
22 the following morning.

23

24

1 **METHODS**

2 *Subjects*

3 Eleven male, amateur, rugby league players volunteered to participate in this study. The mean
4 \pm standard deviation (SD) age, stature and body mass for all participants were 20.4 ± 2.5 y,
5 178.9 ± 5.7 cm and 83.0 ± 11.3 kg. Participants competed at First (n= 7) and Second Grade
6 (n= 4) level in a University grade rugby league competition and reported completing one
7 competitive match, two sports specific skills sessions and two-three strength training sessions
8 per week. Written informed consent was obtained following explanation of all procedures
9 and possible risks involved. All experimentation was approved by the University Ethics in
10 Human Research Committee.

11

12 *Design*

13 Using a randomised, cross-over design participants completed two trials (sleep deprivation
14 (SDEP) vs. control (CONT)) to examine the neuromuscular, cognitive and perceptual
15 recovery the morning after a rugby league match. Participants reported for baseline measures
16 at 08:00 (~7 h pre-match), within 10-20 min immediately post-match, 2 h post-match (at the
17 start of the evening) and the following morning at a standardised time (08:00; 16 h post-
18 match). Accordingly, this study simulated an ecologically valid sporting environment where
19 players may encounter sleep disruption following a match, but are still required to attend
20 recovery sessions the following morning. Participants abstained from exercise and alcohol 24
21 h before, and all caffeine 3 h before each match session and throughout the intervention
22 period. Following the match (intervention period) subjects were provided with a standardised
23 evening meal consisting of energy: $30.5 \text{ kJ} \cdot \text{kg}^{-1}$, carbohydrate: $3.0 \text{ g} \cdot \text{kg}^{-1}$ and protein: $0.9 \text{ g} \cdot \text{kg}^{-1}$

1 ¹) and did not consume additional food until the following morning after 16 h post-match
2 measures. Self-reported physical activity and dietary records were completed for the 24 h
3 before exercise for the initial trial and replicated thereafter.

4

5 *Methodology*

6 Rugby League Match

7 Participants completed an 80 min rugby league match as part of the respective first and
8 second grade teams. Matches used throughout the study were mid-season home games
9 against teams of similar competition standings. During all matches, distance and speed of
10 movement were recorded by 1-Hz Global Positioning Satellite (GPS) (SPI elite, GPSports
11 Systems, Canberra, Australia) devices worn in a customised harness on the cervical
12 vertebrae. Data for distance and mean speeds were reported in the following categories; low-
13 intensity activity (LIA; $<14.4 \text{ km}\cdot\text{h}^{-1}$), high-intensity running (HIR; $>14.5 \text{ km}\cdot\text{h}^{-1}$) and very-
14 high-intensity running (VHIR; $>20 \text{ km}\cdot\text{h}^{-1}$).²⁰ Mean speed ($\text{m}\cdot\text{s}^{-1}$) was calculated based on
15 distance covered divided by time in play. Matches were filmed using a digital video
16 camcorder (Canon MV920, Canon Australia Pty Ltd., Sydney, Australia) positioned at the
17 half-way line of the field. Post-match notational analysis was performed to quantify the
18 number of tackles and hit-ups during the match as defined by the observation of an impact
19 with the opposition player/s as part of carrying the ball or tackling the ball carrier. In
20 addition, a rating of perceived exertion (RPE; Borg CR-10)²¹ was obtained 15 min following
21 each match. While competitive matches were not standardised for work, measures of
22 distance, mean speeds and inter-player contacts allowed comparison of external load between
23 respective matches.

1 Sleep Intervention

2 The two randomised interventions included one night of normal sleep (~8 h; CONT) and one
3 night of no sleep (~0 h; SDEP). Following 2 h post-match measures, participants remained in
4 the laboratory for the ensuing night. A standardised meal was provided at 20:00, following
5 which participants were provided with leisure activities (movies, computers, reading
6 material) until 23:00. In CONT, participants retired to self-provided bedding within the
7 darkened laboratory (0 ± 2 LUX; Lux Light Meter; Digitech; Rydalmere, Australia) by 23:30;
8 while in SDEP participants remained awake and sedentary until the next day in a lit part of
9 the laboratory (80 ± 5 LUX). The laboratory was monitored by the research team and
10 participants were observed to ensure compliance with the respective interventions. Heart rate
11 monitors (Polar Electro-Oy RS232, Kempele, Finland) were worn by all participants during
12 the night to provide an indirect indication of physical activity between conditions. Core
13 temperature (T_{core}) was also recorded, via ingestion of a telemetric capsule (VitalSense, Mini
14 Mitter, Bend, OR, USA) at approximately 10:30 to allow passage into the digestive tract and
15 recorded with a telemetric receiver (VitalSense, Mini Mitter, Bend, OR, USA). Respective
16 HR and T_{core} measures were recorded at 30 min intervals throughout the night from 20:00
17 until 08:00 the following morning without waking participants.

18

19 *Measures*

20 Neuromuscular Performance

21 Participants completed a repeated countermovement jump (CMJ) protocol pre-, post-, 2 h
22 post- and 16 h post-match as a measure of lower-body power output. Following a 5 min
23 warm-up on a cycle ergometer (Ergomedic 828E Monark, Sweden) at 80 rpm with 2 kp

1 resistance (apart from post-match), participants completed 10 maximal CMJ repetitions. Peak
2 distance was measured using a linear position transducer (G1706374B; Fitness Technology,
3 Adelaide, Australia) attached to a dowel rod positioned across the shoulders and interfaced
4 with specialised software (Ballistic Measurement System Software, Fitness Technology,
5 Adelaide, Australia). The typical error of distance for this measure has been previously
6 reported as 0.023 m for elite athletes²² and the coefficient of variation for sub-elite, college
7 athletes CMJ distance has been reported as 2.8%.²³

8

9 Maximal voluntary contraction (MVC) and voluntary activation (VA) of the right knee
10 extensors were assessed using an isokinetic dynamometer (Kincom, Model 125, Chattanooga
11 Group Inc, Hixon, USA). Subjects were seated and strapped to the dynamometer across the
12 chest, hips and near the ankle (1.0 cm above the lateral malleolus) on the right leg, with arms
13 crossed to isolate movement of the right knee extensors. Participants' hip and knee position
14 were kept consistent between sessions. Muscle activation was achieved using a double felt-tip
15 electrode (Bipolar felt-tip electrode, Cardinal Health, Madison, WI, USA) placed over the
16 femoral nerve on the anterior thigh 1.0 cm below the inguinal fold. The electrical stimulus
17 was delivered via a stimulator (Digitimer Ltd, Welwyn Garden City, Hertfordshire, England)
18 linked to a BNC2100 terminal block and connected to a signal acquisition system (PXI1024;
19 National Instruments, Austin, Texas, USA) which sampled all data at 2000Hz. Electrical
20 stimulus was delivered using a single square-wave pulse with a width of 200 μ s, which was
21 driven using customised software (v8.0, LabView; National Instruments, Austin, USA).

22

23 Initially the current was applied in incremental steps until a plateau in peak twitch torque, and
24 was then increased by 10% to ensure supramaximal stimulation. Six resting evoked twitches

1 were delivered to the femoral nerve before participants completed isometric contractions at
2 60%, 80% and 100% of maximal effort. The MVC protocol consisted of 15 x 3 s maximal
3 isometric contractions of the right knee extensors with a 6s recovery between each
4 contraction.⁹ The initial and final five contractions were superimposed with an electrical
5 stimulus when peak torque was achieved and a potentiated twitch was delivered immediately
6 post contraction when the muscle. Peak MVC was determined as the mean torque produced
7 during the MVC in the 50 ms prior to the delivery of the stimulus. Voluntary activation (VA)
8 was calculated using the twitch interpolation technique.²⁴

9

10 Physiological

11 Nude body mass was recorded pre-, 2 h post- and 16 h post-match on a set of calibrated
12 scales (BE-150K Scales, A&D, Thebarton, Australia). Participants also provided a mid-
13 stream urine sample to measure urine specific gravity (USG) to indicate hydration status
14 (Refractometer 503, Nippon, Tokyo, Japan). Urine output was also measured throughout the
15 intervention period via collection of urine output in a jar that was weighed to determine total
16 urine volume (BE-150K Scales, A&D, Thebarton, Australia).

17

18 Venous blood was collected at each time point using an evacuated venipuncture system and
19 serum separator tubes (BD Vacutainer, Sydney, Australia) and analysed for creatine kinase
20 (CK) and C-reactive protein (CRP) as markers of muscle damage and inflammation. Samples
21 were allowed to clot at room temperature before centrifugation (4000 rpm at 4°C for 10 min),
22 with serum stored at -20°C until analysis according to assay instructions (Siemens Healthcare
23 Diagnostics Inc., Newark, USA). CK concentrations were determined using an enzymatic

1 method and bichromatic rate technique. CRP samples were manually diluted according to
2 manufacturer's instructions and analysed with the particle enhanced turbidimetric
3 immunoassay technique (PETIA).

4

5 Perceptual and Cognitive Measures

6 Cognitive function was measured at all time points using a modified version of the Colour-
7 Word Stroop Test.²⁵ This computer-based test of cognitive function required subjects to react
8 to repeated colour and word stimuli, analysing response time, accuracy and total duration for
9 congruent (CRT) and incongruent (IRT) word-colour stimuli responses. Questions answered
10 incorrectly were repeated during the test causing an increase in total test time. The acceptable
11 reliability of the modified Stroop test has been previously reported with reliability
12 coefficients of 0.71-0.79.²⁶ Finally, perceptual muscle soreness (MS) (0= normal – 10=
13 extremely sore) was assessed pre-, post-, 2 h post- and 16 h post-match.

14

15 *Statistical Analysis*

16 Data are reported as mean \pm standard deviation (SD). A repeated measures two-way ANOVA
17 (condition x time) was used to determine significant differences for time and time by group,
18 within and between each condition, with significance at $P < 0.05$. Effect sizes (Cohen's d)
19 were calculated to analyse the magnitude of effect of the sleep intervention, with < 0.20
20 considered 'trivial', 0.20–0.39 as 'small', 0.40–0.79 as 'moderate', and > 0.80 as 'large'.
21 Given the inability to standardise the work completed during the match, a paired t-test was
22 also used to determine significant differences in the percentage change of measures from
23 post- to 16 h post-match, as this is the duration of time in which the intervention was

1 imposed. All analyses were conducted using Statistical Package for Social Sciences (SPSS,
2 v17.0, Chicago, USA).

3

4 **RESULTS**

5 *Match Loads and Neuromuscular Performance*

6 All GPS parameters, inter-player contacts and RPE data are presented in Table 1. There were
7 no significant differences observed between conditions for any match load variables ($P=$
8 0.09–0.74). However, moderate-to-large effects demonstrated a higher mean speed ($d= 0.87$)
9 and peak speed ($d= 0.48$) during SDEP trials. This greater match speed reflected a moderately
10 higher RPE in the SDEP condition ($d= 0.52$), with trivial-to-small effects observed between
11 conditions in all remaining match-load variables ($d= 0.11$ –0.24).

12

13 Changes in MVC did not significantly differ between conditions, demonstrating trivial-to-
14 small effects at all time points ($P= 0.40$ –0.75; $d= 0.13$ –0.33; Table 2). Significant differences
15 and moderate-to-large effects indicated a reduced MVC in both conditions 2 h and 16 h post-
16 match compared to pre-match values ($P= 0.01$ –0.02; $d= 0.63$ –1.30). Further, MVC were
17 significantly lower than post-match measures within SDEP trials at the 2 h and 16 h time
18 points ($P= 0.02$; $d= 0.67$ –0.76). There were no significant differences and trivial-to-moderate
19 effects in VA between ($P= 0.25$ –0.76; $d= 0.16$ –0.56; Table 2) and within conditions over
20 time ($P= 0.12$ –0.76; $d= 0.14$ –0.66). Notably, large effects for a reduced percentage change in
21 post- to 16 h post-match VA were evident in SDEP trials compared to CONT ($P= 0.19$; $d=$
22 0.84).

1 While no significant differences and small effects were apparent in mean and peak CMJ
2 distances between conditions pre-match ($P= 0.52-0.63$; $d= 0.34-0.38$), large effects denoted
3 higher mean and peak CMJ performance in SDEP trials post- ($d= 0.81-0.97$) and 2 h post-
4 match ($d= 0.96-1.18$). In contrast, SDEP moderately lowered peak CMJ distance compared
5 to CONT 16 h post-match ($d= 0.45$), and similarly demonstrated larger percentage declines in
6 mean and peak CMJ performance from post- to 16 h post-match than CONT trials ($P= 0.10-$
7 0.16 ; $d= 0.95-1.05$).

8

9 *Physiological*

10 Significant differences and large effects were observed for a higher T_{core} between the hours of
11 02:00 – 04:00 during SDEP compared to CONT ($P= 0.004-0.04$; $d= 0.83-3.38$; Figure 1).
12 Similarly, there were significant differences and large effects between conditions indicating
13 an elevated HR during the hours of 23:30 – 07:00 during SDEP ($P= 0.01-0.04$; $d= 0.80-3.19$;
14 Figure 1). Both conditions demonstrated significant change and large effects for HR and T_{core}
15 over time ($P= 0.001-0.03$; $d= 1.52-5.62$).

16

17 Measures of USG demonstrated no significant differences and small and moderate effects
18 between conditions pre- (CONT: 1.022 ± 0.006 vs. SDEP: 1.022 ± 0.005 ; $P= 0.62$; $d= 0.23$)
19 and 2 h post-match (CONT: 1.027 ± 0.007 vs. SDEP 1.025 ± 0.009 ; $P= 0.07$; $d= 0.52$),
20 respectively. Large effects did indicate lower USG 16 h post-match in SDEP compared to
21 CONT (CONT: 1.022 ± 0.006 vs. SDEP 1.019 ± 0.005 ; $P= 0.11$; $d= 0.86$). The SDEP
22 intervention elicited no significant changes and trivial-to-small effects in total urine output
23 (CONT: 1.16 ± 0.53 kg vs. SDEP: 1.05 ± 0.40 kg; $P= 0.98$; $d= 0.32$) and nude mass recorded

1 pre- (CONT: 83.04 ± 11.26 vs. SDEP: 83.84 ± 10.82 kg; $P= 0.11$; $d= 0.10$), post- (CONT:
2 82.52 ± 11.39 vs. SDEP: 83.71 ± 11.32 kg; $P= 0.09$; $d= 0.15$), 2 h post- (CONT: $82.95 \pm$
3 11.51 vs. SDEP: 83.71 ± 11.01 kg; $P= 0.13$; $d= 0.10$) and 16 h post-match (CONT: $83.04 \pm$
4 11.59 vs. SDEP: 84.38 ± 11.07 kg; $P= 0.08$; $d= 0.17$), respectively.

6 *Biochemical*

7 Neither CK nor CRP significantly differed between conditions at any time point ($P= 0.11$ –
8 0.87 ; Figure 2). However, moderate and large effects were apparent to demonstrate elevated
9 CK 2h post- ($d= 0.65$) and 16 h post-match ($d= 0.80$) in the SDEP trial compared to CONT,
10 respectively. Additionally, SDEP educed moderate and large effects for higher CRP values
11 than CONT post- ($d= 0.48$) and 16 h post-match ($d= 0.88$), respectively. Competitive rugby
12 league significantly increased CK at all time points compared to pre-match values ($P= 0.001$ –
13 0.03 ; $d= 1.66$ – 2.31), and although these findings were not reflected in CRP ($P= 0.20$ – 0.87),
14 both conditions demonstrated largely higher values than baseline 16 h post-match ($d= 0.81$ –
15 1.69).

17 *Cognitive and Perceptual*

18 Measures of cognitive recovery are presented in Table 3. Post- to 16 h post-match percentage
19 change in IRT word-colour stimuli responses were significantly slower during SDEP trials
20 ($P= 0.007$; $d= 1.75$), despite large effects to demonstrate a lower decline in total time
21 compared to CONT ($P= 0.05$; $d= 1.31$). There were no significant differences and only small-
22 to-moderate effects between conditions in total test time ($P= 0.07$ – 0.47 ; $d= 0.25$ – 0.70) and
23 CRT word-colour stimuli responses ($P= 0.10$ – 0.70 ; $d= 0.17$ – 0.68). Finally, although largely

1 higher pre-match muscle soreness were apparent in CONT ($P= 0.18$; $d= 0.93$; Figure 2), no
2 significant differences and trivial-to-moderate effects were detected between conditions at all
3 other time points ($P= 0.37$ – 0.59 ; $d= 0.16$ – 0.50). Significant differences and large effects
4 within both conditions indicate increased muscle soreness at all time points compared to pre-
5 match ratings ($P= 0.001$ – 0.02 ; $d= 1.31$ – 4.23).

6

7 **DISCUSSION**

8 This study examined the effect of overnight sleep deprivation on the recovery of
9 neuromuscular, physiological and cognitive function the morning after a rugby league match.
10 Importantly, these data show one night's sleep deprivation following a competitive rugby
11 league match to delay the recovery of lower-body power (mean and peak CMJ distance) up to
12 16 h post-match, despite similar declines in isolated MVC between conditions. Furthermore,
13 sleep deprivation slowed recovery of reaction time responses for colour to word cognitive
14 tasks. The mechanisms responsible for slowed CMJ and cognitive recovery may be
15 associated with the trends of reduced VA and increased CK and CRP release following sleep
16 deprivation. Furthermore, as previously suggested,^{12-13,19} the inability to blind subjects to the
17 respective conditions (CONT vs. SDEP) may have also influenced recovery, creating a
18 negative placebo environment. Regardless, sleep deprivation following competitive rugby
19 league matches can negatively affect post-match recovery of CMJ distance and cognitive
20 function.

21

22 The context of this study reflects a common issue for team sports; whereby post-match
23 demands reduce sleep prior to ensuing morning recovery sessions. The present study used a

1 competitive 'real world' environment to determine the effects of sleep deprivation on
2 recovery; however, such an environment also presents a limitation in that a non-standardised
3 bout of exercise was performed. However, GPS data demonstrates similar external match
4 loads between conditions, with no differences in distances covered, mean speeds or high
5 intensity running. A further limitation of the present study was the absence of actigraphy
6 measures to objectively record sleep volume, however measurement of HR and T_{core} were
7 used as an alternative indication of activity. While acknowledged as only surrogate measures,
8 elevated HR and T_{core} responses throughout the evening of the SDEP condition highlight the
9 absence of sleep and a disruption to the sleep-wake cycle.²⁷

10

11 The reduced percentage change in CMJ from post- to 16 h post-match (the duration of the
12 sleep intervention) suggests a blunted recovery of lower-body power following SDEP
13 compared to CONT. Such delayed recovery in peak power is consistent with Takeuchi et al.²⁸
14 who also reported slower 40m sprint times, reductions in vertical jump distance and
15 isokinetic leg extension force (60 and 180°·s⁻¹) following 64 h sleep deprivation. Similarly,
16 Souissi et al.¹¹ examined lower-body power using the 30 s Wingate test and reported a
17 reduction in peak and mean power output during the subsequent afternoon (36 h sleep
18 deprivation) but no effect during morning testing (24 h sleep deprivation). The mechanisms
19 responsible for the differences in percentage change within the present study may be
20 associated with the trend for reduced neural drive (VA) to the active musculature and the
21 increased skeletal muscle damage (CK and CRP) resulting in suppressed recovery of lower-
22 body power. However, the lack of significant between-condition differences of these
23 aforementioned variables may be due to shorter duration of sleep deprivation, as previous
24 studies have reported extended sleep deprivation protocols greater than 30 h.¹¹⁻²⁷

1 Furthermore, suppression of recovery following SDEP may also be due to the inability to
2 blind subjects from the respective conditions (SDEP vs. CONT) and the knowledge of being
3 sleep deprived may have had a placebo effect on lower-body power.¹³ Regardless, the current
4 study suggests the recovery of lower-body power may be suppressed by sleep loss following
5 rugby matches.

6

7 Peak MVC was reduced in both conditions following the rugby league match, further
8 highlighting the effect of match demands on skeletal muscle force production.³⁻⁴ While rugby
9 league matches reduced MVC post-match, a lack of difference between conditions in post- to
10 16 h post-match percentage change indicate that recovery of isolated-joint MVC torque was
11 minimally affected by sleep deprivation per se. These findings are contrary to Skein et al.¹³
12 who reported reductions in MVC and VA after 30 h sleep deprivation, with neuromuscular
13 function measured in the afternoon following the intervention. As mentioned previously, the
14 shorter sleep deprivation duration (24 h) in the current study may explain the lack of
15 difference in MVC torque between conditions. Furthermore, the trends for a greater reduction
16 in VA following sleep loss despite minimal effects on MVC suggests that other factors
17 associated with sleep deprivation i.e. the knowledge of being in a sleep deprived state,
18 increased perceptual stress, increased metabolic activity and cognitive impairment may have
19 influenced recovery of dynamic lower-body power, with limited effect on isolated muscle
20 contractile force.

21

22 Competitive rugby league can invoke substantial structural damage to muscular tissue.²⁹ The
23 progressive increase in CK following the match is an indirect indication of muscle damage.²⁹⁻

24 ³⁰ Although not significantly different between conditions, large effect sizes suggest a greater

1 rise in CK following sleep deprivation. However the variation in CK between players and in
2 the match results in high variability,²⁹⁻³⁰ potentially impacting on the lack of significance.
3 Similar to CK, moderate-to-large effect sizes also suggest trends for increased CRP following
4 sleep loss, further highlighting that sleep loss may have a negative effect on the recovery of
5 muscle damage markers following competitive matches. Sleep is known to enhance anabolic
6 processes, particularly in the presence of tissue damage,¹⁶ and may account for the observed
7 trends in lowered CK and CRP responses following a night's sleep. However, a lack of
8 statistical significance may also be due to post-match CK requiring ~72 h to return to
9 baseline^{28,30} and therefore an insufficient duration to monitor post-match responses was
10 available in the present study. Accordingly, while the above findings indicate the presence of
11 muscle damage following the rugby league match, trends indicate 24 h sleep deprivation can
12 delay the recovery of post-match skeletal muscle damage markers; though longer sleep
13 deprivation duration may be required, to observe statistical significance.¹¹⁻¹³

14

15 Finally, cognitive function is an important factor during training and competition football and
16 was assessed in the present study via a modified Stroop test.²⁵ Results suggest the cognitive
17 response time to word-colour stimuli were negatively affected the morning following sleep
18 deprivation. Furthermore, large effect sizes also suggest total reaction time and congruent
19 reaction time were also slowed by 24 h sleep deprivation. Such findings corroborate previous
20 studies reporting reaction time to be significantly slower after sleep deprivation³² and suggest
21 that sleep deprivation can reduce alertness and attention; ultimately causing a reduction in
22 reaction time to simple and choice cognitive tasks.³² These slowed cognitive responses
23 following sleep deprivation have been suggested to be more apparent in simple tasks that
24 involve minimal environmental stimulation.³³ While it is not suggested such simple word-

1 colour tasks represent the cognitive demands of training or competitive football, the
2 controlled context of the laboratory allows some suggestion that response times to visual
3 stimuli may be affected by sleep loss.³² Accordingly, post-match sleep deprivation may result
4 in altered cognitive functioning the following morning, which may affect attention and
5 decision making skills during ensuing training sessions.

6

7 In summary, the present data highlight the detrimental effects of sleep deprivation on next-
8 day recovery following a competitive rugby league match. Sleep loss increased
9 cardiovascular and thermal loads during the night, and slowed cognitive responses the next
10 morning highlighting the altered physiological load of wakefulness. Whether these
11 exacerbated physiological and cognitive loads results in the blunted recovery of lower-body
12 power (CMJ distance) observed the following morning remains unknown. While differences
13 in CMJ percentage change were evident between conditions, the lack of difference in
14 absolute values and the minimal effect on MVC may be a time of day effect; in that sleep
15 deprivation induces greater decrements later in the day with a longer duration awake.
16 Regardless, practitioners should note that the loss of sleep during the night following
17 competitive matches may result in players presenting for next-day sessions with augmented
18 physical fatigue, slower cognitive function and some suppression of lower-body power.

19

20 Practical applications

21 Despite the extreme nature of sleep deprivation used here, post-match sleep loss following
22 competitive matches' results in augmented physical fatigue, slower cognitive function and
23 lower-body power suppression. As such, players may present for training sessions in the

1 following morning in a sub-optimal state of preparedness for training. Accordingly,
2 avoidance of sleep deprivation is recommended for rugby league players, along with tailoring
3 training sessions to suit the state of the players based on the specificity of the circumstances.

4

1 REFERENCES

- 2 1. Gabbett TJ. Influence of physiological characteristics on selection in a semi-professional
3 first grade rugby league team: a case study. *J Sports Sci.* 2002;20:399-405.
- 4 2. Gabbett TJ. Science of rugby league football: A review. *J Sports Sci.* 2005; 23(9):961-
5 976.
- 6 3. Duffield R, Murphy A, Snape A, Minett GM, Skein M. Post-match changes in
7 neuromuscular function and the relationship to match demands in amateur rugby league
8 matches. *J Sci Med Sport.* 2012;15(3):238-43.
- 9 4. McLellan CP, Lovell DI, Gass GC. Markers of postmatch fatigue in professional Rugby
10 League players. *J Strength Cond Res.* 2011;25(4):1030-1039.
- 11 5. Bishop D. The effects of travel on team performance in the Australian national netball
12 competition. *J Sci Med Sport.* 2004;7(1):118-122.
- 13 6. Halson, SL. Nutrition, sleep and recovery. *Euro J Sport Sci.* 2008;8(2): 119-126.
- 14 7. Richmond L, Dawson B, Hillman DR, Eastwood P. The effect of interstate travel on sleep
15 patterns of elite Australian Rules footballers. *J Sci Med Sport.* 2004;7(2):186-196.
- 16 8. Sargent C, Halson S, Roach GD. Sleep or swim? Early-morning training severely restricts
17 the amount of sleep obtained by elite swimmers. *Euro J Sport Sci.* 2012;DOI:
18 10.1080/17461391.2012.696711.
- 19 9. Martin BJ, Chen H. Sleep loss and the sympathoadrenal response to exercise. *Med Sci*
20 *Sports Exerc.* 1984;16(1):56.
- 21 10. Reilly T, Piercy M. The effect of partial sleep deprivation on weight-lifting performance.
22 *Ergonomics.* 1994;37(1):107-115.
- 23 11. Souissi N, Sesbotié B, Gauthier A, Larue J, Davenne D. Effects of one night's sleep
24 deprivation on anaerobic performance the following day. *Eur J Appl Physiol.*
25 2003;89(3):359-366

- 1 12. Oliver SJ, Costa RJS, Laing SJ, Bilzon JJJ, Walsh NP. One night of sleep deprivation
2 decreases treadmill endurance performance. *Eur J Appl Physiol.* 2009;107:155-161.
- 3 13. Skein M, Duffield R, Edge J, Short M, Mündel T. Intermittent-sprint performance and
4 muscle glycogen following 30 h sleep deprivation. *Med Sci Sports Exerc.*
5 2011;43(7):1301-1311.
- 6 14. Chen H. Effects of 30-h sleep loss on cardiorespiratory functions at rest and in exercise.
7 *Med Sci Sports Exerc.* 1991;23(2)193.
- 8 15. Sawka MN, Gonzalez RR, Pandolf KB. Effects of sleep deprivation on thermoregulation
9 during exercise. *Am J Physiol- Reg, Integr Comp Physiol.* 1984;246(1):72-77.
- 10 16. Adam K, Oswald I. Sleep helps healing. *Brit Med J.* 1984;289: 56-64.
- 11 17. Meney I, Waterhouse J, Atkinson G, Reilly T, Davenne D. The effect of one night's sleep
12 deprivation on temperature, mood, and physical performance in subjects with different
13 amounts of habitual physical activity. *Chronobiology International.* 1998;15(4): 349-363.
- 14 18. Myles WS. Sleep deprivation, physical fatigue, and the perception of exercise intensity.
15 *Med Sci Sports Exerc.* 1985;17(5):580.
- 16 19. Martin BJ. Effect of sleep deprivation on tolerance of prolonged exercise. *Eur J of Appl*
17 *Physiol.* 1981;47(4):345-354.
- 18 20. Coutts AJ, Duffield R. Validity and reliability of GPS units for measuring movement
19 demands of team sports. *J Sci Med Sport.* 2010;13(1):133–135.
- 20 21. Borg G, Ljunggren G, Ceci R. The increase of perceived exertion, aches and pain in the
21 legs, heart rate and blood lactate during exercise on a bicycle ergometer. *Eur J Appl*
22 *Physiol.* 1985;54(4):343-349.
- 23 22. Cormack SJ, Newton RU, McGuigan MR, Doyle TLA. Reliability of measures obtained
24 during single and repeated countermovement jumps. *Int J Sports Physiol Perform.*
25 2008;3:131-144.

- 1 23. Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and factorial validity of squat
2 and countermovement jump tests. *J Strength Cond Res.* 2004;18(3):551-555.
- 3 24. Merton PA. Voluntary strength and fatigue. *J. Physiol.* 1954;123:553-564.
- 4 25. Stroop JR. Studies of interference in serial verbal reactions. *J Exp Psych.* 1932;18:643-
5 662.
- 6 26. Strauss GP, Allen DN, Jorgensen ML, Cramer SL. Test-retest reliability of standard and
7 emotional stroop tasks: an investigation of color-word and picture-word versions.
8 *Assessment.* 2005;12(3):330-337.
- 9 27. Waterhouse J, Drust B, Weinert D, Edwards B, Gregson W, Atkinson G, Kao S, Aizawa
10 S, Reilly T. The circadian rhythm of core temperature: origin and some implications for
11 exercise. *Chronobiol Int.* 2005;22(2):207–225.
- 12 28. Takeuchi L, Davis GM, Plyley M, Goode R, Shephard RJ. Sleep deprivation, chronic
13 exercise and muscular performance. *Ergonomics.* 1985;28(3):591-601.
- 14 29. McLellan CP, Lovell DI, Gass GC. Creatine Kinase and endocrine responses of elite
15 players pre, during and post rugby league match play. *J Strength Cond Res.* 2010;24(11):
16 2908–2919.
- 17 30. Minett G, Duffield R, Bird SP. Effects of acute multinutrient supplementation on rugby
18 union game performance and recovery. *Int J Sports Physiol Perf.* 2010;5:27-41.
- 19 31. Takarada Y. Evaluation of muscle damage after a rugby match with special reference to
20 tackle plays. *Brit J Sports Med.* 2003;37(5):416-419.
- 21 32. Sagaspe P, Sanchez-Ortuno M, Charles A, Taillard J, Valtat C, Bioulac B, Philip P.
22 Effects of sleep deprivation on Color-Word, Emotional, and Specific Stroop interference
23 and on self-reported anxiety. *Brain and Cognition.* 2006;60(1): 76-87.
- 24 33. Van Dongen HP, Dinges DF. Sleep, circadian rhythms, and psychomotor vigilance. *Clin*
25 *Sports Med.* 2005;24(2):237-249.
- 26

1 **Figure and Table Captions**

2 **Figure 1:** Mean \pm SD A) core temperature and B) heart rate over the intervention night for
3 control (CONT) and sleep deprivation (SDEP) conditions. * Significant difference between
4 conditions ($P < 0.05$). ^a Large effect size between conditions ($d > 0.80$).

5

6 **Figure 2:** Mean \pm SD A) Creatine Kinase (CK), B) C-reactive protein (CRP) and C)
7 perceived muscle soreness (MS) for control (CONT) and sleep deprivation (SDEP)
8 conditions. * Significant difference between conditions. ^a Large effect size between
9 conditions ($d > 0.80$). ^b Moderate effect size between conditions ($d = 0.40-0.79$).

10

11 **Table 1: Match loads during competitive rugby league matches for each condition**
12 **(control vs sleep deprivation) including total distance covered during the match, mean**
13 **speed; distance covered during high-intensity running and very-high intensity running,**
14 **peak speed during the match, number of contacts and perceived exertion.**

15 CONT: control; HIR: high intensity running; RPE: rating of perceived exertion; VHIR: very
16 high intensity running; SDEP: sleep deprivation.

17 No significant differences between conditions. ^a Large effect size between conditions
18 ($d > 0.80$). ^b Moderate effect size between conditions ($d = 0.40-0.79$).

19

20 **Table 2: Summary of absolute neuromuscular performance including maximal**
21 **voluntary contractions, voluntary activation, peak and mean distance during counter-**
22 **movement and relative change from post-match to 16h post-match for control and sleep**
23 **deprivation conditions.**

24 CMJ: counter-movement jump; CONT: control; MVC: maximal voluntary contraction;
25 SDEP; sleep deprivation; VA: voluntary activation.

26 * Significantly different between conditions ($p < 0.05$). # Significantly different to pre-match
27 values ($P < 0.05$). ^ Significantly different to post-match values ($P < 0.05$). ^a Large effect size
28 between conditions ($d > 0.80$). ^b Moderate effect size between conditions ($d = 0.40-0.79$)

29

30

31

32 **Table 3. Summary of cognition results including total test time, congruent word-colour**
33 **reaction time and incongruent word-colour reaction time for control and sleep**
34 **deprivation conditions during a modified Stroop test and percentage change from post-**
35 **match to 16h post-match.**

36 CONT: control; CRT: congruent word-colour reaction time; IRT: incongruent word-colour
37 reaction time; SDEP; sleep deprivation

38 * Significantly different between conditions ($P < 0.05$). ^a Large effect size between conditions
39 ($d > 0.80$). ^b Moderate effect size between conditions ($d = 0.40-0.79$).