International Journal of Kinesiology & Sports Science
ISSN: 2202-946X
www.ijkss.aiac.org.au

Does Sleep Quality between Back-to-Back Matches Influence Running Performance in Canadian Female University Soccer Players? A GPS-based Time-Series Analysis

David Turczyn[1], Diana McMillan[2], Phillip F. Gardiner[1,3], Stephen M. Cornish[1]*

[1]*Faculty of Kinesiology and Recreation Management, University of Manitoba, Winnipeg, Canada*
[2]*College of Nursing, Rady Faculty of Health Sciences, University of Manitoba, Winnipeg, Canada*
[3]*Spinal Cord Research Centre, University of Manitoba, Winnipeg, Canada*

Corresponding Author: Stephen M. Cornish, E-mail: Stephen.Cornish@umanitoba.ca

ARTICLE INFO

Article history
Received: October 10, 2021
Accepted: January 13, 2022
Published: January 30, 2022
Volume: 10 Issue: 1

Conflicts of interest: None
Funding: No funding was provided for this study.

ABSTRACT

Background: Soccer competitions performed with less than or equal to 24 hours of recuperation, including inadequate amounts of quality sleep, may adversely affect performance. **Objective:** The purpose of this research was to assess running performance between self-reported good and poor sleepers in female university sport soccer players (N = 12) in matches played with ≤ 24 hours of recovery. **Methods:** In this cross-sectional and observational study, twelve female university soccer players (mean age: 19.44 + 1.69 yr) were followed throughout one season of competition using a time-series analysis of running performance and comparing good (n = 7) versus poor (n = 5) sleepers. Global positioning systems (GPS) were used to evaluate jogging/sprinting performance throughout the 2016 soccer season. Good and poor sleepers were determined via the Pittsburgh Sleep Quality Index (PSQI). **Results:** There was a significant reduction (p <.05) in running performance from the first to the second game in the entire cohort, while post hoc analysis indicated that good sleepers performed better on the relative speed performance parameter when comparing the first game to the second game; however, there was no change in this performance variable in the poor sleepers between the first and second game. **Conclusions:** Our study indicates that Canadian female university soccer players may need longer than 24 hours of recovery to perform optimally in subsequent matches. Generally, good and poor sleepers perform similarly except for GPS relative speed in back-to-back matches with 24 hours of recovery.

Key words: Running, Sleep, Athletic Performance, Sports, Sleep Hygiene, Recovery of Function

INTRODUCTION

Inadequate recovery due to strenuous athletic training and/or competition has been described as overreaching which, if perpetuated, leads to overtraining and alterations in many physiological systems but, foremostly leading to underperformance (Budgett 1998; Meeusen et al. 2013). Both psychological and physical stress from training and competition can lead to overreaching (i.e., imbalances in athletic performance, school work, sleep, and work) (Kennedy, Tamminen, and Holt 2013). Frequent competitions and lengthy training requirements as well as a lack of good sleep hygiene may promote under-recovery in athletes (Budgett 1998; Ritchie et al. 2016). Thus, having good sleep hygiene and balancing training, competition, performance, and nonperformance strains is deemed essential for the health of the individual athlete. Many studies have focused on overreaching in individual endurance-based sports; however, there is minimal research on this topic in team sports (Meeusen et al. 2013).

The physical fitness demands of soccer are very high (Krustrup et al. 2005). Professional soccer athletes cover distances between 9-13 km in one game (Andersson et al. 2010; Bangsbo, Mohr, and Krustrup 2006; Krustrup et al. 2005). Previous reports have identified that female university level soccer players cover distances between 8-11 km in one game and that high-intensity running accounts for a large proportion of this total distance (McCormack et al. 2014; Vescovi and Favero 2014). In addition, soccer performance requires many eccentric muscle actions due to jumping, kicking, changes of direction, accelerations, and decelerations which produces damage to skeletal muscle (Andersson et al. 2008; Nédélec et al. 2015; Varley and Aughey 2013). As soccer games proceed, there is an amplification in dehydration, damage to skeletal muscle, and glycogen depletion which results in a decrement in running performance (Akenhead et al. 2013; Krustrup et al. 2011). Various athletic performance parameters such as maximal voluntary contraction, sprint performance, and jump performance are negatively affected by up to 72 hours due to the fatigue generated with one soccer match (Andersson et al. 2008; Krustrup et al. 2011; Nédélec et al. 2015).

Proper sleep hygiene is a significant component of recovery for high performance athletes (Charest and

Published by Australian International Academic Centre PTY.LTD.

http://dx.doi.org/10.7575/aiac.ijkss.v.10n.1p.9

Grandner 2020; Doherty et al. 2021). Sleep quality and quantity can be negatively affected in high performance athletes with many of them reporting sleep disturbances that will negatively affect athletic performance outcomes (Gupta, Morgan, Gilchrist 2017). Sleep, in general, and slow-wave sleep (SWS) or deep sleep, specifically, are deemed essential for athlete recovery following strenuous high-intensity activity (Simpson, Gibbs, and Matheson 2017; Taylor, Rogers, and Driver 1997; Vitale et al. 2019). SWS is essential for adequate growth hormone release and the promotion of anabolic conditions which would aid athlete recovery (Bolin 2019; Juliff, Halson, and Peiffer 2015; Malhotra 2017; Shapiro et al. 1981). Sleep deprivation will decrease SWS, increase daytime tiredness, and reduce performance (Dijk 2010). If people spend less than seven hours asleep, psychomotor vigilance task performance, such as reaction time, will decrease substantially and progressively with increasing sleep restriction (Belenky et al. 2003; Dinges et al. 1997; Lim and Dinges 2008; Van Dongen et al. 2003). With sleep restriction, neurobehavioral functions progressively decrease in a dose response trajectory; however, individual awareness of sleepiness is distorted with progressive sleep constraints (Simpson et al. 2016; Van Dongen et al. 2003). Restricting sleep will have a negative effect on athletic performance in a variety of athletes, including those athletes that compete in soccer (Bolin 2019; Malhotra 2017; Simpson et al. 2017; Vitale et al. 2019), and it was found that 64% of a diverse range of athletes have sleep disturbances the night before a competition (Juliff et al. 2015).

Canadian university sports require female soccer athletes to play two games each weekend with less than or equal to 24 hours of recuperation between them in a condensed schedule over the regular season of 7-weeks. The risk of overreaching or overtraining is high in these athletes due to the lack of recovery between games over the course of the season. This may be exacerbated with poor sleep between matches. The research aim was to describe the differences in various running parameters between Canadian university female soccer athletes deemed either good or poor sleepers over one competitive season. The primary hypothesis was that GPS assessed running performance variables would be significantly less when comparing the second game to the first game in matches played within 24 hours of one another. Secondarily, it was hypothesized that poor sleepers, as indicated by the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al. 1989), would perform worse when compared to good sleepers in higher intensity running variables as assessed by GPS.

MATERIALS AND METHODS

Participants and Study Design

This study used an observational and cross-sectional design and recruited a convenience sample of twelve university caliber outfield female soccer players from one Canadian university team. Age (years), height (cm), weight (kg), and length in university (years) were all assessed at the beginning of the season. The participants were tracked using the GPS systems for seven weekends over which the team participated in competitions; however, only five of those weekends met the criteria for inclusion in the data analysis as there was ≤ 24 hours between these matches. The other two weekends included games with > 24 hours of rest between matches and were excluded from the analysis. The inclusion criteria for the study was that each participant had to participate in a minimum of ≥ 45 minutes of game play in each of the matches assessed and that they had to be a part of the university female soccer team. Exclusion criteria for the study included any musculoskeletal injuries that would preclude their participation in competitions and less than 45 minutes of playing time in each of the competitions where GPS variables were assessed. The lifestyle habits of the participants were not overtly monitored in this research; nevertheless, they were instructed to not deviate from their normal activities (i.e., drinking alcohol, smoking, medication use, and dietary intake). The independent variable in this study was sleep quality as assessed by the PSQI (i.e., good or poor sleep). The dependent variables in this study were various running performance parameters as assessed by the GPS systems the athletes wore during competition (see below for explanation). The Human Research Ethics Board at the University of Manitoba (protocol number: HS20602) approved this study. Further, all participants provided written informed consent.

Global Positioning System

Global Positioning System (GPS) equipment containing an accelerometer capable of attaining movements at 100Hz (SPI HPU, 15 Hz, GPSport, Canberra, Australia), were activated and secured in the outdoor docking station 30 minutes prior to warm-ups of games so that individual athletes could retrieve their specific device. A tight-fitting vest was used to secure the GPS devices to the mid-back of the athletes for all the participants before the match so they could be tracked by the device throughout the game. The participants returned their respective GPS units and vests to the investigator after each match was complete. Each participants data was downloaded and split into the different game components (i.e., warm-up, first-half, half-time, and second-half). This data was then exported to a spreadsheet using Excel software. Previous techniques completed by McCormack et al. (2015), were used to breakdown the data for each one of the matches similarly for the current study. For all players that participated in at least 45 minutes for each game was averaged over the entire season (i.e., for the five weekend back-to-back matches).

The zones of speed were classified as low-intensity running (Zone one: 0-11.9 km/hr), moderate intensity running (Zone two: 12-15.9 km/hr), high-intensity running one (Zone three: 16-17.9 km/hr), high-intensity running two (Zone four: 18-19.9 km/hr), high-intensity running three (Zone five: 20-22.9 km/hr) and high-intensity running four (Zone six: > 23 km/hr). The number of sprints performed in each game was the principal dependent variable used from the GPS devices in the data analysis as this involves the key performance quality needed to create and stop scoring chances during a soccer match (Di Salvo et al. 2009, 2010; Reilly, Bangsbo, and Franks 2000; Varley and Aughey 2013). A sprint was expressed by a running velocity ≥ 23 km/hr lasting a minimum of one second. Secondary running performance variables evaluated in this research included: the total number of decelerations and accelerations, the high-intensity running distance (m), the relative distance covered (in m·min^{-1}), and the total running distance (m). The entire cohort of athletes was able to reach the sprint speed running velocity of 23 km/hr based on a 40-meter sprint speed test at the beginning of the season. Running in zones three or higher (i.e., ≥ 16 km/hr) was delineated as running at high-intensity. We summated any high-intensity running that was ≥ 16 km/hr, which included zone 3-6.

Using previous research by Akenhead et al. (2013), the deceleration and acceleration counts were defined using the thresholds of high acceleration (HA; Zone three; >3 m·s^{-2}), medium acceleration (MA; Zone two; from 2 to 3 m·s^{-2}), low acceleration (LA; Zone one; from 1 to 2 m·s^{-2}), high deceleration (HD; Zone three; > -3 m·s^{-2}), medium deceleration (MD; Zone two; from -3 to -2 m·s^{-2}), and low deceleration (LD; Zone one; from -2 to -1 m·s^{-2}). The summation of all zones of the number of accelerations were calculated to give a total acceleration number. Total number of decelerations were calculated in the same manner.

Sleep Assessment

The assessment of global sleep quality and quantity was performed by using the Pittsburgh Sleep Quality Index (PSQI). It is an instrument that effectively assesses sleep and persistent sleep disturbances in research participants (Buysse et al. 1989). The PSQI assesses seven areas related to sleep: daytime dysfunction, use of sleeping medications, sleep disturbances, habitual sleep efficiency, sleep duration, sleep latency, and subjective sleep quality. A global PSQI score is assigned by calculating the sum of the seven components of the questionnaire, which ranges from 0-21, with higher scores indicative of poorer sleep quality. PSQI scores > 5 indicate that there are moderate to severe difficulties with sleep hygiene. We used previously published data to indicate "good" (≤ 5 on PSQI) or "poor" (> 5 on PSQI) sleepers (Buysse et al. 1989).

Statistical Analyses

All data was collected and reported as mean ± SD for each day evaluated and for all performance variables as assessed by the GPS units. Differences between the minutes played, number of decelerations and accelerations performed at different zones, number of sprints performed, high intensity running, and mean relative distance rate (total distance travelled divided by the total minutes played) during the first match (Game 1: G1) and second match (Game 2: G2) throughout the regular season were analyzed using a two-factor group (poor versus good sleepers) by time (G1 versus G2) repeated measures analysis of variance (ANOVA). TIBCO STATISTICA version 13.3 (StatSoft, Tulsa, Oklahoma, USA) software was used to statistically analyze all the data. Significance was set at $p \leq .05$.

RESULTS

There was a total of 12 female University Sport soccer players from the University of Manitoba that participated in this study (Mean ± SD: age 19.44 ± 1.69 years old, height 162.41 ± 4.56 cm, weight 60.38 ± 4.39 kg, years in university 2 ± 1.04, PSQI score 6.17 ± 3.49). Based on PSQI scores, 5 of 12 players, or 41.7% of participants were considered to have poor sleep. Athlete baseline data which is separated by self-reported "good" versus "poor" sleepers is presented in Table 1.

A significant group × time interaction effect ($p \leq 0.05$; see Table 2) was noted for relative speed when comparing the differences in GPS variables between poor and good sleepers by repeated measures ANOVA. According to the post hoc analysis, good sleepers (n = 7) had significantly higher mean relative speed in G1 (113.22 + 3.32 m·min^{-1}) compared to G2 (109.16 + 4.33 m·min^{-1}) while poor sleepers (n = 5) did not change in this performance variable (G1: 107.81 + 11.23 m·min^{-1} versus G2: 108.25 + 9.25 m·min^{-1}). Thus, good sleepers generally performed at higher mean relative speed when "fresh" but became similar to poor sleepers following a subsequent match ≤ 24 hours later. There was no main effect for group in this data set (all p >.05); however, there were significant time main effects ($p \leq .05$; see Table 2) for all GPS variables analyzed except for deceleration in zone one (p >.05; see Table 2) where the GPS performance variables all decreased from G1 to G2.

DISCUSSION

The use of GPS tracking systems to evaluate multiple running performance variables in a team of university caliber female soccer athletes with only 24 hours of recovery between two games, while at the same time evaluating self-reported sleep quantity and quality, makes this study unique. To our knowledge, this is the first study that evaluated the performance of various running parameters as assessed by GPS from G1 to G2 with ≤ 24 hours of recovery between soccer games. Running performance variables were significantly reduced between G1 and G2 for the entire cohort in support of our primary hypothesis. Our second hypothesis was partially supported where good sleepers performed at a higher mean relative speed in G1 when they were likely better rested as compared to G2. Further, it is interesting to

Table 1. Baseline data of female university soccer players

Variable	Good Sleepers (n = 7)	Poor Sleepers (n = 5)
Age (years)	19.01±0.99	20.94±1.81*
Height (cm)	163.71±5.06	160.6±3.44
Weight (kg)	60.77±5.12	59.84±3.62
Years in University	1.57±0.79	2.60±1.14
PSQI scores	2.80±0.84	8.57±2.37*

* Significantly higher than good sleepers, p < 0.05; all values are displayed as mean±standard deviation

Table 2. Comparison of mean global positioning system (GPS) running variables from game 1 (G1) to game 2 (G2) in good and poor sleepers within female university sport soccer players

Variables	**G1**	**G2**	***P*-Value**		
			Time	**Group**	**Time × Group**
Duration (min)					
Good	84.82±7.43	82.51±9.81	0.009*	0.701	0.094
Poor	89.49±4.98	81.03±5.17			
Relative speed (m·min^{-1})					
Good	113.22±3.32	109.16±4.33	0.040*	0.460	0.015**
Poor	107.81±11.23	108.25±9.25			
Total Distance (m)					
Good	9576.15±625.32	9019.49±729.16	<.001*	0.847	0.198
Poor	9641.41±716.74	8778.82±1081.18			
Distance Zone one (m)					
Good	6736.92±534.75	6554.67±726.39	0.004*	0.665	0.082
Poor	6807.24±290.85	6221.08±356.8			
Distance Zone two (m)					
Good	1902.50±124.61	1679.86±107.65	<.001*	0.534	0.404
Poor	1775.54±390.19	1605.21±422.45			
Distance Zone three (m)					
Good	448.63±38.35	381.19±36.96	<.001*	0.707	0.212
Poor	459.76±151.32	417.35±169.73			
Distance Zone four (m)					
Good	263.06±28.00	214.27±34.81	<.001*	0.442	0.133
Poor	287.22±100.15	258.54±119.42			
Distance Zone five (m)					
Good	174.32±32.31	147.03±27.08	0.002*	0.258	0.239
Poor	212.05+88.62	197.80±98.63			
Distance Zone six (m)					
Good	50.73±11.23	42.46±5.91	0.003*	0.178	0.131
Poor	99.59±84.89	78.83±73.64			
Distance Zone three through six (m)					
Good	936.73±101.27	784.95±96.94	<.001*	0.365	0.160
Poor	1058.62±374.94	952.53±415.87			
Sprint Count (#)					
Good	5.61±1.39	3.98±0.33	<.001*	0.198	0.811
Poor	8.05±4.71	6.28±4.38			
Sprint Distance (m)					
Good	257.63±67.03	199.40±17.18	0.004*	0.217	0.741
Poor	357.45±203.81	309.09±216.64			
Accelerations Zone one (#)					
Good	340.50±34.35	330.75±35.86	0.010*	0.592	0.139
Poor	341.41±17.79	311.51±23.65			
Accelerations Zone two (#)					
Good	93.53±12.86	86.54±10.38	<.001*	0.640	0.668
Poor	97.32±9.75	89.04±12.16			
Accelerations Zone three (#)					
Good	22.57±6.72	19.66±4.04	0.003*	0.272	0.629

(Contd...)

Table 2. *(Continued)*

Variables	G1	G2	*P*-Value		
			Time	Group	Time × Group
Poor	26.45±5.74	22.64±3.77			
Total Accelerations (#)					
Good	456.61±47.82	436.95±39.63	0.002*	0.909	0.173
Poor	465.19±28.59	423.19±38.32			
Decelerations Zone one (#)					
Good	276.90±33.43	273.73±29.46	0.071	0.689	0.171
Poor	279.37±20.31	258.97±18.83			
Decelerations Zone two (#)					
Good	92.33±12.30	85.66±9.13	0.001*	0.814	0.835
Poor	90.71±15.76	83.37±19.89			
Decelerations Zone three (#)					
Good	37.10±9.70	31.80±6.75	<.001*	0.363	0.321
Poor	44.03±14.21	35.83±9.95			
Total Decelerations (#)					
Good	406.33±45.03	391.19±35.70	0.003*	0.906	0.161
Poor	414.11±27.48	378.17±44.02			

All values are displayed as mean ± standard deviation. G1 = Game 1; G2 = Game 2
[a]Good sleepers $n = 7$.
[b]Poor sleepers $n = 5$.
*Indicates significant main effect of time $p < 0.05$
**Indicates significant reduction in good sleepers $p \leq 0.05$

note that 41.7% of our cohort reported poor global sleep (i.e., were poor sleepers) which is an interesting finding as these athletes were young and healthy adults and it would not be expected to find such a high incidence of poor sleep in this cohort.

A previous study (McCormack et al. 2015) found that high intensity running/minute of competition in female university soccer players was reduced when evaluated between two games played with approximately 42 hours of rest between them. Although our study evaluated soccer games played with ≤ 24 hours of recovery between them, we did not evaluate HIR/min; however, we did evaluate HIR as an absolute value and it significantly decreased from G1 to G2 thus, providing further evidence of the decrease observed in running performance when matches are played with shortened recovery times between them. The current study found that the number and duration of sprints as well as relative speed were all lowered significantly from G1 to G2; though, McCormack et al. (2015), indicated that sprint number, relative speed, and duration did not significantly differ from Friday to Sunday games. The differences between the two studies may be explained by the length of recovery between games (24 hours versus 42 hours) and contrasting methods between GPS HIR speed zones. McCormack et al. (2015) used 12.9 km/hr to delineate a cut-off for HIR while our study was set to ≥ 16 km/hr.

As for the significant time × group interaction that was noted in our study for relative speed, where poor sleepers' relative speed did not decrease between matches but, good sleepers relative speed did decrease between G1 and G2, it should be highlighted that good sleepers had a relative speed performance that was higher when compared to poor sleepers (on average 4.7% higher in G1 and 0.8% higher in G2). This could translate into approximately between 82 to 487 meters more distance travelled in a 90-minute match. Although speculative, this increased distance that a player could travel in a game may result in more scoring opportunities for the good sleepers. Further, based on relative speed performance, sleepers deemed good were likely better rested for G1 and thus performed better than poor sleepers. The good sleepers performed better in G1 versus G2 thus, suggesting that better self-reported sleep may effectively improve performance in at least the first game of two played with approximately 24 hours of rest between them. Also, although not statistically significant, the good sleepers performed better in regard to relative speed throughout both games suggesting that good sleepers may potentially recover more effectively between matches played with 24 hours of rest between them. It may be that good sleepers did not properly pace themselves between G1 and G2 thus, demonstrating a significant decrease in relative intensity between the two games. The number of first year players in the good sleep categorization was higher than the number of first year players in the poor sleep category (four versus one, respectively; data not shown) thus, this could indicate an increased deficiency in the technical or tactical aspects of the game, increasing the likelihood of making errors in performance, which could result in increased distance run throughout the match. Finally, Di Salvo et al. (2009) recognized that running distance that a soccer athlete runs is position specific thus, as our study contained an uneven distribution of good sleepers that were attacking players (data not shown) versus poor sleepers, the relative speed results could be explained by this factor.

There are several mechanisms that exist explaining the G1 to G2 decrease in running performance in this study. Primarily, one mechanism that could be influencing the loss of performance from G1 to G2 is that partial sleep deprivation between games could be influencing the repair and recovery processes to ensure optimal performance in the second game as compared to the first game. It is well known that poor sleep affects the ability of athletes to recover from the strenuous exercise they participate in and will negatively affect performance (Malhotra 2017; Nédélec et al. 2015; Vitale et al. 2019). It may be that both the good and poor sleepers in this study had poor sleep between the two games played with minimal rest between them. Thus, partial sleep deprivation may explain some of the decreases observed between G1 and G2 in running performance.

Secondly, a 2% body weight loss due to dehydration (fluid loss) has been previously noted in female soccer players that are highly trained (Andersson et al. 2008; Krustrup et al. 2005, 2011). According to Shirreffs et al. (1996) it takes ~6 hours to rehydrate after fluid loss of this extent. Rehydration strategies after prolonged exercise should include consuming 150% of the sweat lost with fluids and consuming fluids that contain 61 mmol/L sodium concentration to ensure adequate recovery. Thus, it is highly unlikely that dehydration plays a major role in fatigue between matches played with 24 hours of recovery between them as most athletes consume adequate amounts of fluids in this time-period. A more plausible explanation is that glycogen re-synthesis is affected by rehydration as it plays a role in increasing intracellular fluid volume, thus directly influencing the rates of glycogen and protein synthesis (Keller et al. 2003; Waller et al. 2009). Thus, low intracellular volume will mean lower re-synthesis rates while high cell volume may accelerate the re-synthesis rates.

Thirdly, glycogen depletion throughout a soccer match likely influences the quantity of high-intensity running that can be accomplished (Bangsbo et al. 2006; Krustrup et al. 2011). Regardless of the level of competition, soccer specific studies indicate that muscle glycogen stores are decreased substantially after a match and remain so for up to between 48 to 72 hours post-match (Jacobs et al. 1982; Krustrup et al. 2011). Furthermore, Asp et al. (1998) reported that damage to skeletal muscle induced by eccentric muscle action resulted in low muscle glycogen content when compared to controls. The lower glycogen storage is attributed to delayed glycogen re-synthesis due to the muscle damage caused by the eccentric exercise. The complete restoration of muscle glycogen stores following a soccer match with ≤ 24 hours of recovery is deemed very difficult. Skeletal muscle actions producing movements such as sprinting and high-intensity running are likely negatively affected for up to 72 hours after a soccer game (Fatouros et al. 2010; Mohr et al. 2016). Further, it is known that sleep deprivation negatively affects glucose metabolism which may influence exercise performance in an adverse manner (VanHelder and Radomski 1989).

Finally, the high-intensity activities involved in soccer, including the many eccentric muscle actions, results in skeletal muscle damage (Nédélec et al. 2015; Opar, Williams, and Shield 2012). Muscle damage results in alterations to the banding patterns of myofibrillar proteins, damage to the muscle fiber, and damage to the sarcolemma all of which culminates in loss of force production by the skeletal muscle (Clarkson, Nosaka, and Braun 1992). As mentioned, muscle actions that are eccentric in nature result in decreases in muscle performance, increases in indirect blood biomarkers of muscle damage (for example: creatine kinase and myoglobin), and delayed onset of muscle soreness which negatively affects exercise ability (Howatson and van Someren 2008; Krustrup et al. 2011; Mohr et al. 2016; Nédélec et al. 2015). This is the first study, to our knowledge, that has reported significant decreases in running performance as assessed by GPS devices when games are played with ≤ 24 hours of recovery.

There are several strengths associated with our study. First, tracking female university soccer athletes using the GPS devices throughout an entire competitive season is viewed as a strength as we did not simulate matches to collect our data. This has the strength of being extremely generalizable to the population of university female athletes who participate in soccer matches with ≤ 24 hours of recuperation between them. Second, using the PSQI questionnaire to subjectively evaluate our participants as good or poor sleepers is relatively unique in an athletic population. This allowed us to observe if good or poor sleepers would perform differently in relation to the GPS running variables we analyzed in this study. Finally, our study collected in-season data in a longitudinal fashion which provides a broader picture of how athletes perform throughout an entire season versus just a snapshot of the season (i.e., 1 or 2 games). Practically, our study has a few implications. Coaches should be aware of their athletes sleep hygiene as it may influence relative speed performance between games played back-to-back with ≤ 24 hours of recovery. Further, coaches should consider substituting players into the first and second games more frequently to account for the decrease in performance observed between games played with ≤ 24 hours of rest between them. This may aid the team in improving the performance observed in the second match when compared to the first. Overall, coaches should try to implement good sleep hygiene practices for their athletes and implement player rotation more frequently to account for performance decrements in the second match when games are played with ≤ 24 hours of recuperation between them.

This research is not without limitations. One limitation is that only one retrospective questionnaire was used to evaluate sleep quality in our entire cohort. While this is viewed as a limitation, the PSQI measurement tool offers a reliable method of evaluating global sleep hygiene but may have failed to capture the immediate effects of a poor night's sleep on soccer game performance. Studies offering both global and daily sleep assessments, as well as objective and subjective sleep evaluations, may enhance our understanding of the effects that sleep hygiene may have on performance in female university soccer athletes. Secondly, we just collected data over

10 games that were played with ≤ 24 hours of recuperation between them over a complete regular season in one female university soccer team. Our sample size is low and we have a limited amount of game data that was collected for this study; however, this is common practice in athletic populations. In the future, studies should evaluate a larger number of athlete participants and include a variety of teams and/or increase the number of seasons that are evaluated within the context of this congested competition schedule. Improving on the statistical power by collecting data over multiple seasons and increasing the number of participants that could be analyzed is suggested as a future research priority. Also, this study did not include analysis of video performance to evaluate if tactical or technical errors made by the athletes may have contributed to our results. Finally, we did not collect performance data from the opponents in each of the respective games thus, we are unable to evaluate if opponents outperformed the athletes on our team of interest in each match.

CONCLUSION

In summary, female university soccer athletes show a decrease in running performance, as assessed by GPS, between two weekend matches played with ≤ 24 hours of rest between them. Relative speed was demonstrated to be higher in "good" sleepers in the first match of two played over the weekend but, this variable decreased to levels similar to "poor" sleepers' performance by the second match. No other running performance variables were different between "good" and "poor" sleepers in our cohort. Further research evaluating "good" and "poor" sleepers in an assortment of athletic events is warranted to understand the effects that poor sleep may have on athletic performance outcomes. By rotating players between soccer halves and between matches, practitioners and coaches may be able to reduce the risk of declining running performance observed in a second match played with ≤ 24 hours of recovery from the first match.

ACKNOWLEDGEMENTS

The authors wish to thank all the participants for their time and effort in helping to complete this study. Special thanks to Dr. Vanessa Martinez Lagunas for her role in facilitating the opportunity for this research study. This manuscript was extracted from the thesis of the primary author at the University of Manitoba.

AUTHORS' CONTRIBUTION

All authors designed the research protocol. DT conducted the experiment and analyzed the data. DT and SMC wrote the manuscript. All authors worked on revising the manuscript for submission. All authors read and approved the final version of the manuscript.

REFERENCES

Akenhead, Richard, Philip R. Hayes, Kevin G. Thompson, and Duncan French. 2013. Diminutions of Acceleration and Deceleration Output during Professional Football Match Play. *Journal of Science and Medicine in Sport.* 16(6):556–61. doi: 10.1016/j.jsams.2012.12.005.

Andersson, Helena A., Morten B. Randers, Anja Heiner-Møller, Peter Krustrup, and Magni Mohr. 2010. Elite Female Soccer Players Perform More High-Intensity Running When Playing in International Games Compared with Domestic League Games. *Journal of Strength and Conditioning Research.* 24(4):912–19. doi: 10.1519/JSC.0b013e3181d09f21.

Andersson, Helena, Truls Raastad, Johnny Nilsson, Gøran Paulsen, Ina Garthe, and Fawzi Kadi. 2008. Neuromuscular Fatigue and Recovery in Elite Female Soccer: Effects of Active Recovery. *Medicine and Science in Sports and Exercise.* 40(2):372–80. doi: 10.1249/mss.0b013e31815b8497.

Asp, S., J. R. Daugaard, S. Kristiansen, B. Kiens, and E. A. Richter. 1998. Exercise Metabolism in Human Skeletal Muscle Exposed to Prior Eccentric Exercise. *The Journal of Physiology.* 509 (Pt 1):305–13. doi: 10.1111/j.1469-7793.1998.305bo.x.

Bangsbo, Jens, Magni Mohr, and Peter Krustrup. 2006. Physical and Metabolic Demands of Training and Match-Play in the Elite Football Player. *Journal of Sports Sciences.* 24(7):665–74. doi: 10.1080/02640410500482529.

Bolin, Delmas J. 2019. Sleep Deprivation and Its Contribution to Mood and Performance Deterioration in College Athletes. *Current Sports Medicine Reports.* 18(8):305–10. doi: 10.1249/JSR.0000000000000621.

Budgett, R. 1998. Fatigue and Underperformance in Athletes: The Overtraining Syndrome. *British Journal of Sports Medicine.* 32(2):107–10. doi: 10.1136/bjsm.32.2.107.

Buysse, D. J., C. F. Reynolds, T. H. Monk, S. R. Berman, and D. J. Kupfer. 1989. The Pittsburgh Sleep Quality Index: A New Instrument for Psychiatric Practice and Research. *Psychiatry Research.* 28(2):193–213. doi: 10.1016/0165-1781(89)90047-4.

Charest, J., and M.A. Grandner. 2020. Sleep and Athletic Performance: Impacts on Physical Performance, Mental Performance, Injury Risk and Recovery, and Mental Health. *Sleep Medicine Clinics.* 15(1):41-57. doi: 10.1016/j.jsmc.2019.11.005.

Clarkson, P. M., K. Nosaka, and B. Braun. 1992. Muscle Function after Exercise-Induced Muscle Damage and Rapid Adaptation. *Medicine and Science in Sports and Exercise.* 24(5):512–20.

Di Salvo, V., W. Gregson, G. Atkinson, P. Tordoff, and B. Drust. 2009. Analysis of High Intensity Activity in Premier League Soccer. *International Journal of Sports Medicine.* 30(3):205–12. doi: 10.1055/s-0028-1105950.

Di Salvo, Valter, Ramon Baron, Carlos González-Haro, Christian Gormasz, Fabio Pigozzi, and Norbert Bachl. 2010. Sprinting Analysis of Elite Soccer Players during European Champions League and UEFA Cup Matches. *Journal of Sports Sciences.* 28(14):1489–94. doi: 10.1080/02640414.2010.521166.

Dinges, D. F., F. Pack, K. Williams, K. A. Gillen, J. W. Powell, G. E. Ott, C. Aptowicz, and A. I. Pack. 1997.

Cumulative Sleepiness, Mood Disturbance, and Psychomotor Vigilance Performance Decrements during a Week of Sleep Restricted to 4-5 Hours per Night. *Sleep.* 20(4):267–77.

Doherty, R., S.M. Madigan, A. Nevill, G. Warrington, and J.G. Ellis. 2021. The Sleep and Recovery Practices of Athletes. *Nutrients*. 13(4):1330. doi: 10.3390/nu13041330.

Fatouros, Ioannis G., Athanasios Chatzinikolaou, Ioannis I. Douroudos, Michalis G. Nikolaidis, Antonios Kyparos, Konstantinos Margonis, Yiannis Michailidis, Antonios Vantarakis, Kyriakos Taxildaris, Ioannis Katrabasas, Dimitrios Mandalidis, Dimitrios Kouretas, and Athanasios Z. Jamurtas. 2010. Time-Course of Changes in Oxidative Stress and Antioxidant Status Responses Following a Soccer Game. *Journal of Strength and Conditioning Research.* 24(12):3278–86. doi: 10.1519/JSC.0b013e3181b60444.

Gupta, L., K. Morgan, and S. Gilchrist. 2017. Does Elite Sport Degrade Sleep Quality? A Systematic Review.
Sports Medicine. 47(7):1317-1333. doi: 10.1007/s40279-016-0650-6.

Howatson, Glyn, and Ken A. van Someren. 2008. The Prevention and Treatment of Exercise-Induced Muscle Damage. *Sports Medicine (Auckland, N.Z.).* 38(6):483–503. doi: 10.2165/00007256-200838060-00004.

Jacobs, I., N. Westlin, J. Karlsson, M. Rasmusson, and B. Houghton. 1982. Muscle Glycogen and Diet in Elite Soccer Players. *European Journal of Applied Physiology and Occupational Physiology.* 48(3):297–302. doi: 10.1007/bf00430219.

Juliff, Laura E., Shona L. Halson, and Jeremiah J. Peiffer. 2015. Understanding Sleep Disturbance in Athletes Prior to Important Competitions. *Journal of Science and Medicine in Sport.* 18(1):13–18. doi: 10.1016/j.jsams.2014.02.007.

Keller, U., G. Szinnai, S. Bilz, and K. Berneis. 2003. Effects of Changes in Hydration on Protein, Glucose and Lipid Metabolism in Man: Impact on Health. *European Journal of Clinical Nutrition.* 57 Suppl 2:S69-74. doi: 10.1038/sj.ejcn.1601904.

Kennedy, Michael D., Katherine A. Tamminen, and Nicholas L. Holt. 2013. Factors That Influence Fatigue Status in Canadian University Swimmers. *Journal of Sports Sciences.* 31(5):554–64. doi: 10.1080/02640414.2012.738927.

Krustrup, Peter, Magni Mohr, Helga Ellingsgaard, and Jens Bangsbo. 2005. Physical Demands during an Elite Female Soccer Game: Importance of Training Status. *Medicine and Science in Sports and Exercise.* 37(7):1242–48. doi: 10.1249/01.mss.0000170062.73981.94.

Krustrup, Peter, Niels Ortenblad, Joachim Nielsen, Lars Nybo, Thomas P. Gunnarsson, F. Marcello Iaia, Klavs Madsen, Francis Stephens, Paul Greenhaff, and Jens Bangsbo. 2011. Maximal Voluntary Contraction Force, SR Function and Glycogen Resynthesis during the First 72 h after a High-Level Competitive Soccer Game. *European Journal of Applied Physiology.* 111(12):2987–95. doi: 10.1007/s00421-011-1919-y.

Lim, Julian, and David F. Dinges. 2008. Sleep Deprivation and Vigilant Attention. *Annals of the New York Academy of Sciences.* 1129:305–22. doi: 10.1196/annals.1417.002.

Malhotra, Raman K. 2017. Sleep, Recovery, and Performance in Sports. *Neurologic Clinics.* 35(3):547–57. doi: 10.1016/j.ncl.2017.03.002.

McCormack, William P., Jay R. Hoffman, Gabriel J. Pruna, Tyler C. Scanlon, Jonathan D. Bohner, Jeremy R. Townsend, Adam R. Jajtner, Jeffrey R. Stout, Maren S. Fragala, and David H. Fukuda. 2015. Reduced High-Intensity-Running Rate in Collegiate Women's Soccer When Games Are Separated by 42 Hours. *International Journal of Sports Physiology and Performance.* 10(4):436–39. doi: 10.1123/ijspp.2014-0336.

McCormack, William P., Jeffrey R. Stout, Adam J. Wells, Adam M. Gonzalez, Gerald T. Mangine, Maren S. Fragala, and Jay R. Hoffman. 2014. Predictors of High-Intensity Running Capacity in Collegiate Women during a Soccer Game. *Journal of Strength and Conditioning Research.* 28(4):964–70. doi: 10.1519/JSC.0000000000000359.

Meeusen, Romain, Martine Duclos, Carl Foster, Andrew Fry, Michael Gleeson, David Nieman, John Raglin, Gerard Rietjens, Jürgen Steinacker, Axel Urhausen, European College of Sport Science, and American College of Sports Medicine. 2013. Prevention, Diagnosis, and Treatment of the Overtraining Syndrome: Joint Consensus Statement of the European College of Sport Science and the American College of Sports Medicine. *Medicine and Science in Sports and Exercise.* 45(1):186–205. doi: 10.1249/MSS.0b013e318279a10a.

Mohr, Magni, Dimitrios Draganidis, Athanasios Chatzinikolaou, Jose Carlos Barbero-Álvarez, Carlo Castagna, Ioannis Douroudos, Alexandra Avloniti, Alexandra Margeli, Ioannis Papassotiriou, Andreas D. Flouris, Athanasios Z. Jamurtas, Peter Krustrup, and Ioannis G. Fatouros. 2016. Muscle Damage, Inflammatory, Immune and Performance Responses to Three Football Games in 1 Week in Competitive Male Players. *European Journal of Applied Physiology.* 116(1):179–93. doi: 10.1007/s00421-015-3245-2.

Nédélec, Mathieu, Shona Halson, Abd-Elbasset Abaidia, Said Ahmaidi, and Gregory Dupont. 2015. Stress, Sleep and Recovery in Elite Soccer: A Critical Review of the Literature. *Sports Medicine (Auckland, N.Z.).* 45(10):1387–1400. doi: 10.1007/s40279-015-0358-z.

Opar, David A., Morgan D. Williams, and Anthony J. Shield. 2012. Hamstring Strain Injuries: Factors That Lead to Injury and Re-Injury. *Sports Medicine (Auckland, N.Z.).* 42(3):209–26. doi: 10.2165/11594800-000000000-00000.

Reilly, T., J. Bangsbo, and A. Franks. 2000. Anthropometric and Physiological Predispositions for Elite Soccer. *Journal of Sports Sciences.* 18(9):669–83. doi: 10.1080/02640410050120050.

Ritchie, Dean, Will G. Hopkins, Martin Buchheit, Justin Cordy, and Jonathan D. Bartlett. 2016. Quantification of Training and Competition Load Across a Season in an

Elite Australian Football Club. *International Journal of Sports Physiology and Performance.* 11(4):474–79. doi: 10.1123/ijspp.2015-0294.

Shapiro, C. M., R. Bortz, D. Mitchell, P. Bartel, and P. Jooste. 1981. Slow-Wave Sleep: A Recovery Period after Exercise. *Science (New York, N.Y.).* 214(4526):1253–54. doi: 10.1126/science.7302594.

Shirreffs, S. M., A. J. Taylor, J. B. Leiper, and R. J. Maughan. 1996. Post-Exercise Rehydration in Man: Effects of Volume Consumed and Drink Sodium Content. *Medicine and Science in Sports and Exercise.* 28(10):1260–71. doi: 10.1097/00005768-199610000-00009.

Simpson, Norah S., Moussa Diolombi, Jennifer Scott-Sutherland, Huan Yang, Vrushank Bhatt, Shiva Gautam, Janet Mullington, and Monika Haack. 2016. Repeating Patterns of Sleep Restriction and Recovery: Do We Get Used to It? *Brain, Behavior, and Immunity.* 58:142–51. doi: 10.1016/j.bbi.2016.06.001.

Taylor, S. R., G. G. Rogers, and H. S. Driver. 1997. Effects of Training Volume on Sleep, Psychological, and Selected Physiological Profiles of Elite Female Swimmers. *Medicine and Science in Sports and Exercise.* 29(5):688–93. doi: 10.1097/00005768-199705000-00016.

Van Dongen, Hans P. A., Greg Maislin, Janet M. Mullington, and David F. Dinges. 2003. The Cumulative Cost of Additional Wakefulness: Dose-Response Effects on Neurobehavioral Functions and Sleep Physiology from Chronic Sleep Restriction and Total Sleep Deprivation. *Sleep.* 26(2):117–26. doi: 10.1093/sleep/26.2.117.

VanHelder, T., and M. W. Radomski. 1989. Sleep Deprivation and the Effect on Exercise Performance. *Sports Medicine (Auckland, N.Z.).* 7(4):235–47. doi: 10.2165/00007256-198907040-00002.

Varley, M. C., and R. J. Aughey. 2013. Acceleration Profiles in Elite Australian Soccer. *International Journal of Sports Medicine.* 34(1):34–39. doi: 10.1055/s-0032-1316315.

Vescovi, Jason D., and Terence G. Favero. 2014. Motion Characteristics of Women's College Soccer Matches: Female Athletes in Motion (FAiM) Study. *International Journal of Sports Physiology and Performance.* 9(3):405–14. doi: 10.1123/IJSPP.2013-0526.

Vitale, Kenneth C., Roberts Owens, Susan R. Hopkins, and Atul Malhotra. 2019. Sleep Hygiene for Optimizing Recovery in Athletes: Review and Recommendations. *International Journal of Sports Medicine.* 40(8):535–43. doi: 10.1055/a-0905-3103.

Waller, Amanda P., George J. F. Heigenhauser, Raymond J. Geor, Lawrence L. Spriet, and Michael I. Lindinger. 2009. Fluid and Electrolyte Supplementation after Prolonged Moderate-Intensity Exercise Enhances Muscle Glycogen Resynthesis in Standardbred Horses. *Journal of Applied Physiology (Bethesda, Md.: 1985).* 106(1):91–100. doi: 10.1152/japplphysiol.90783.2008.