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Monitoring Sleep and Heart Rate in Female Soccer

Cardiac autonomic function and sleep patterns after training sessions and matches in female soccer players

Júlio Alejandro Henriques da Costa

Porto, 2020

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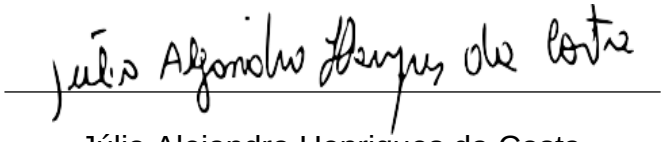
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Attestation authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, or material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.



Júlio Alejandro Henriques da Costa

Porto, 2020

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Resumo

A presente dissertação teve como objetivo investigar o impacto de sessões de treino e de jogos oficiais, realizados em diferentes locais e horas do dia na atividade da função autonómica cardíaca e nos padrões do sono em jogadoras do futebol feminino de diferentes níveis competitivos (elite e semiprofissionais), durante a época desportiva e durante um torneio internacional. No primeiro estudo, foi investigada a sensibilidade da variabilidade da frequência cardíaca (VFC) noturna para avaliar os efeitos de sessões de treino realizadas à noite na função autonómica cardíaca em jogadoras semiprofissionais de futebol. Apesar dos treinos realizados à noite não parecerem influenciar as *slow-wave sleep episode* (SWSE) e os índices da VFC analisados hora-em-hora, ambos os métodos (SWSE e índices da VFC analisados hora-em-hora) mostraram ser medidas de VFC confiáveis, sugerindo que a VFC durante a noite poderá ser sensível (ex. alta capacidade de resposta interna) à resposta aos treinos e jogos. Dado que no primeiro estudo os padrões de sono não foram quantificados através de métodos objetivos, como a actigrafia, foram realizados dois estudos observacionais e longitudinais adicionais em que foram incluídos estes métodos, para avaliar o sono e a VFC noturna em jogadoras semiprofissionais de futebol. Estes estudos permitiram concluir que o horário das sessões (sessões de treino realizadas à noite e os jogos realizados durante o dia) e o local dos jogos (jogos em casa *vs*. fora de casa) podem causar perturbações no padrão de sono e/ou na atividade da função autonómica cardíaca em jogadoras de futebol.

Finalmente, considerando a importância da abordagem individualizada na análise do sono e da VFC noturna após cargas de treino e de jogo, foram realizados um quarto (jogadoras de elite) e quinto (jogadoras semiprofissionais) estudos, focando-se especificamente na análise individual da VFC e dos padrões de sono. Os resultados destes estudos revelaram uma considerável variação individual no sono e da VFC, assim como das cargas de treino e de jogo, informação que deve ser considerada na prescrição de sessões de treino e/ou jogos.

Os resultados da análise observacional da função autonómica cardíaca noturna, dos padrões de sono, e das cargas de treino e de jogo em jogadoras de futebol realizada na presente tese, podem auxiliar treinadores e profissionais clínicos a identificar perturbações da VFC e do sono após treinos e jogos de futebol, o que deverá constituir-se como informação relevante aquando da prescrição individual de cargas de treino e do tempo de jogo no futebol feminino.

Abstract

The present thesis aims to investigate the impact of training sessions and official matches performed at different times of the day and in different locations on autonomic cardiac function and sleep patterns of female soccer players from different competitive levels (elite and semi-professional), during competitive in-season and during an international tournament. The first study investigated the sensitivity of nocturnal heart rate variability (HRV) to evaluate the effects of late-night soccer training sessions on nocturnal autonomic cardiac function of semi-professional female players. Although late-night soccer training did not appear to affect slow-wave sleep episodes (SWSE) and “hour-by-hour” HRV indices analysed, the implementation of both methods resulted in reliable HRV measures, suggesting that overnight HRV could be sensitive (i.e., high-internal responsiveness) to training and matches responses in female soccer players. Since in the first study sleep patterns were not quantified using objective methods such as actigraphy, we conducted two additional observational and longitudinal studies, where these methods were included to assess nocturnal HRV and sleep in semi-professional female players. These studies led to the conclusion that the training and match schedule (i.e., night-training sessions and day matches) and match location (i.e., home-matches vs. away-matches) may cause disruption in sleep patterns and/or in autonomic cardiac activity.

Finally, and considering the importance of an individualized approach in the analysis of sleep and nocturnal HRV from training and match load, a fourth (with elite female players) and fifth (with semi-professionals female players) studies were conducted focusing on individual HRV and sleep patterns. The results of these studies revealed a substantial individual variation in sleep and HRV, as well in training and match load, information that should be considered when prescribing training sessions and/or matches in women’s soccer.

The results of the observational analysis of nocturnal cardiac autonomic function, sleep patterns, and training and match load in female soccer players conducted in this thesis may help coaches and clinical practitioners to identify HRV and sleep disorders after training and matches, which may constitute

relevant information to individually prescribe training load and playing time in female soccer players.

List of Abbreviations

ANS	Autonomic nervous system
HF	High frequency
HR	Heart rate
HR_{max}	Maximum heart rate
HR_{mean}	Average heart rate
HR_{peak}	Peak heart rate
HRV	Heart rate variability
LF	Low frequency
Ln	Natural logarithm
LF/HF	Ratio between low frequency and high frequency
PSG	Polysomnography
RPE	Rate of perceived exertion
RMSSD	Square root of the mean of the sum of the squares of differences between successive normal-to-normal intervals
R–R	Normal-to-normal
SE	Sleep efficiency
s-RPE	Session-rate of perceived exertion
SWSE	Slow-wave sleep episode
TRIMP	Training impulse
TST	Total sleep time

List of Publications

1. Articles in Academic (peer-review) Journals

Costa J.A., Brito J., Nakamura, F. Y., Figueiredo, P., & Rebelo., A. Using the rating of perceived exertion and heart rate to quantify training intensity in female soccer players: validity and utility, *Journal of Strength and Conditioning Research*, 2019: [Epub ahead of print]. doi: 10.1519/JSC.0000000000003407. PubMed PMID: 31593033

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Chapter I

Introduction and rationale

1. General introduction

The popularity of women's sport has increased greatly worldwide over the last few decades. Consequently, the number of international competitions, and professional and recreational sports leagues for women of various age groups, has also increased. This has provided a large number of women with new opportunities to train and compete in sports.

Despite the increased popularity and professionalization, there is still limited scientific research specifically conducted with female athletes compared to their male counterparts, especially in areas related to performance enhancement, fatigue and recovery in different match and training scenarios. For example, in some countries most of the female athletes (professional and non-professional) usually start training sessions at very late hours, close to bedtime sleep, due to their daily life commitments (e.g., job, university). In this scenario, optimizing recovery is required to reduce the risk of transitioning into a state of excessive fatigue as well as to reduce the risk of injury.

The present thesis starts by describing the impact of training sessions and official matches performed at different locations, times of the day and phases of the season (in-season and international tournament), using non-invasive and time-efficient equipment to monitor autonomic cardiac function and sleep patterns in female soccer players. Therefore, it was adopted a "real-world scenario" to grant high ecological validity to the studies presented in the thesis. In this chapter, it is presented the rationale for performing the series of observational/descriptive studies included in the thesis. On the next pages, we will review the current literature in order to develop a theoretical basis for our work.

1.1. Activity profile and physiological demands of female soccer

The growing popularity of female soccer in recent years has contributed to an increase in scientific investigations related to the physical and physiological characteristics of female soccer players. Female players now can train and compete in professional settings, which has given rise to an increase in the

performance expectations placed upon players, and subsequently a need for specific scientific research that could assist in enhancing performance.

Soccer training and match-play impose a range of demands on players, who must have or acquire the necessary capabilities to cope with the specific physical load. During training sessions and matches, high physical demands are imposed on players through performance of technical skills and drills. High levels of activation of different muscle groups are required during body acceleration and deceleration during sudden changes of direction, as well as during explosive jumps and in actions demanding physical contact between players. The repetition of these movements leads to potential decreases in player performance, in a particular action or set of motor actions (Reilly & Ekblom, 2005). Comprehensively, decrements in performance occur more markedly when the players are required to compete and train repeatedly with very short recovery periods (Dupont et al., 2010).

This occurs, especially, in elite soccer players that are constantly exposed to multiple high physiological demands due to an elevated number of training sessions and matches played in National and international competitions, often with congested match calendars (King & Duffield, 2009). In this context (national and international competitions), the knowledge of the match physical and physiological demands, as well as the induced fatigue is of paramount importance to define and optimize recovery strategies to improve player´s physical capacities and minimize performance impairment (Bangsbo et al., 2006; Brink et al., 2011; Dupont et al., 2010).

Female national team players and those competing in the highest domestic leagues are between 20–27 years old, 1.61–1.70 m in stature, weighing 57–65 kg, with a body fat percentage of 14.6–20.1 % and lean muscle mass of 45.7 ± 3.9 kg (Andersson et al., 2010a; Andersson et al., 2010b; Castagna & Castellini, 2013; Gravina et al., 2011; Krustrup et al., 2005; Krustrup et al., 2010). The height and body mass of elite female players have remained stable over the last decades; however, percentage body fat is now lower than previously observed (20.8–22.0 %) (Davis & Brewer, 1993). These alterations in body

composition likely reflect increased training volume and improved access to support staff such as nutritionists and fitness coaches.

Successful evaluation of the physical demands placed upon soccer players requires accurate assessment of both internal and external match demands (Gaudino et al., 2015). Accordingly, the use of wearable technology such as global positioning system devices, simultaneously with heart rate (HR) monitoring, is common in elite sports to monitor the external and internal loads that athletes are submitted to in order to assess movement and physiological demands, respectively (Halson, 2014a). Studies using global positioning system technology found that elite and sub-elite female soccer players cover a total distance of around 8–11 km during a match, ranging between 108–119 and 96–107 meters per minute of play (m/min) for elite and sub-elite players, respectively (Andersson et al., 2010b; Bradley et al., 2014; Hewitt et al., 2014; Mohr et al., 2008; Ramos et al., 2019; Trewin et al., 2018; Vescovi & Favero, 2014), while sprinting and high intensity running constitute 8–12% of the total distance covered (Andersson et al., 2010b; Bradley et al., 2009; Gabbett & Mulvey, 2008; Krustrup et al., 2005; Mohr et al., 2008). Competition level is also important as female players perform more repeated sprint bouts during international matches than in national league matches (Datson et al., 2014). Additionally, female players complete more high-speed running (13 %) and sprinting (14 %) when playing an international match than in a national match (Andersson et al., 2010b). Accordingly, Gabbett and Mulvey (2008) found that the total distance covered was 9968 ± 1143 m in international competitions. The authors also reported that during international matches players spent 16 % of total match time standing, 50 % walking, 27 % jogging, 8 % running at high intensity, 5 % striding, and 3 % sprinting. Very similar results were found by Krustrup et al. (2005) who stated that female players spent 16 % of time standing, 44 % walking, 34 % in low intensity activity, and 5 % running at high intensity. However, there was a wide range of movement patterns dependent on the player's position.

The cardiovascular workload during a female soccer match is relatively high and variable between players (Andersson, 2010). HR measurement is often used as an indirect measure of exercise intensity and applied to examine the internal

load of players during training or competition (Datson et al., 2014). For instance, the amount of time spent in different intensity zones based on the percentage of maximum HR ($HR_{máx}$) is useful to quantify internal match load (Bendiksen et al., 2013). According to Andersson et al. (2010b) and Krustrup et al. (2010), average HR (HR_{mean}) and peak HR (HR_{peak}) can reach 86 ± 3 % and 98 ± 1 % of HR_{max}, respectively. This is an indication that female players experience high aerobic load throughout a match with periods of near-maximal HR values (Andersson et al., 2010b; Krustrup et al., 2010). Significant differences in HR recordings between the first and second half were also reported (Ohlsson et al., 2015; Rampinini et al., 2008). Peak and mean HR recorded during the first half were significantly higher than in the second half (Ohlsson et al., 2015; Rampinini et al., 2008), especially as a consequence of a reduction in the time spent in the intensity zone above 95 % (Ohlsson et al., 2015). Interestingly, HR_{mean} reported in female players was within the same range of values as reported in males (Bangsbo, 1994).

1.2. Fatigue in soccer – acute and chronic responses

The stress associated with training and competition often temporarily impairs player physical performance (Thorpe et al., 2015). This impairment may be acute, lasting minutes or hours, and may stem from metabolic disturbances and substrate utilization associated with high-intensity exercise (Bangsbo et al., 2006). Alternatively, exercise-induced muscle injury and delayed onset muscle soreness which often follow training with a high eccentric component may lead to impairment lasting several days (Thorpe et al., 2015). The balance between the stress imposed by training and competition, and sufficient recovery is therefore of relevant importance since an imbalance over extended periods of time may contribute to potentially long-term debilitating effects associated with overtraining (Nimmo et al., 2007).

As mentioned above, numerous studies have been published reporting that total distance and distance covered in high intensity running and sprinting are lower in the second half than in the first half of the match (Andersson et al.,

2010b; Krustrup et al., 2005; Milanovic et al., 2017; Mohr et al., 2008; Mohr et al., 2003, 2005). According to Mohr et al. (2005), this may indicate that performance is hampered in the second half and that fatigue occurs towards the end of a match. Players also experience temporary fatigue during other periods of the match. A study performed with male soccer players showed that the amount of high intensity running in the 5 min period immediately after the most intense 5 min period recorded during the match is lower than the average of the entire match (Mohr et al*.,* 2003). This decrement in performance after a period of intense exercise could be interpreted as a natural variation in the intensity of matches due to tactical or psychological factors (Krustrup et al., 2006; Mohr et al., 2003). However, when players were asked to perform a repeated sprint test immediately after a short-term intense period during the match the performance in the test was significantly diminished (Mohr *et al.,* 2003). These study results suggest that soccer players experience fatigue temporarily during the match (Krustrup et al., 2006; Mohr et al., 2005).

In female soccer players, the total distance covered has been shown to be consistent between halves (5230 ± 90 vs. 5210 ± 80 m; effect size 0.2) (Datson et al., 2014). However, significant reductions in high-speed running (680 ± 60 vs. 620 ± 40 m; effect size 1.2) and sprinting (200 ± 30 vs. 170 ± 20 m; effect size 1.0) occur. Alterations in match-specific skill involvements between halves were also found, with the number of tackles being greater in the first than in the second half. Another study by Helgerud et al. (2001) showed that the players who presented higher fatigue levels during the match were those who exhibited a significant decrease in the total number of short passes, as well as in the number of successful short passes.

Another way to analyse the occurrence of fatigue among soccer players during competitive matches could be to compare the performance of substitute players, who only participate in parts of the second half, with the performance of players taking part in the entire match. It was observed that substitutes who came on in the second half sprinted and ran at a higher intensity (63 and 25 % more, respectively) than players who played the entire match (Mohr *et al.,* 2003).

1.3. Monitoring training and match load

Soccer players are exposed to greater training volumes and competition demands than ever before (Datson et al., 2014) which may have implications for both physical performance and injury patterns.

Advances in technology available for monitoring athletes has led to greater opportunities to scientifically support players, and, thus, information regarding the modern (elite) female player is increasingly available. Over the years, numerous techniques have been used to determine the physical and physiological profiles of soccer players (Casamichana et al., 2012; Di Salvo et al., 2007; Halson, 2014a; Mallo & Navarro, 2008). However, not all coaches and scientists engage in athlete monitoring (Halson, 2014a). For some athletes/teams/squads, insufficient resources can be a major reason for not including a system of training and match monitoring. Resources may be in the form of time, money, or the human resources needed to collect, process, and analyse the data.

The quantification of training and match load is generally based on both external (e.g., distance, power output, number of repetitions) and internal (e.g., oxygen uptake, HR, blood lactate, rate of perceived exertion [RPE], sleep duration and quality) indicators of effort and intensity, which are then computed with training and match time to derive compound training and match load measures such as training impulse (TRIMP) using HR (Banister & Hamilton, 1985) and session-RPE (s-RPE) using perceived load (Foster, 1998). When it comes to monitoring athlete fatigue and/or performance responses to their training and match loads, there are various tools and methods available, such as monitoring saliva and specific blood variables (Heisterberg et al., 2013; Meeusen et al., 2013), or the use of psychometric questionnaires (Borresen & Lambert, 2009; Buchheit et al., 2013; Hooper & Mackinnon, 1995). Changes in exercise blood lactate might be used to track changes in fitness (Beneke et al., 2011), however, whether they can inform on fatigue *per se* is still under debate (Le Meur et al., 2013; Meeusen et al., 2013). Moreover, blood sampling may be painful and are inconvenient for frequent monitoring.

1.4. Monitoring health parameters

There is increasing the interest in monitoring the status of the autonomic nervous system (ANS) via measures of HR, including the level and variability of HR at rest (Plews et al., 2013; Stanley et al., 2013a), during exercise (Buchheit et al., 2010; Buchheit et al., 2012; Garvican et al., 2014; Rowsell et al., 2009), and following exercise (Buchheit et al., 2010; Buchheit et al., 2008; Buchheit et al., 2013; Buchheit et al., 2012). The main interest in heart rate variability (HRV) measures is that they are non-invasive, inexpensive, time-efficient, and can be applied routinely and simultaneously in many athletes. While the collection of (beat-by-beat) HRV was initially only possible with expensive laboratory-based electrocardiograph recorders, the recent availability of valid and portable recorders such as HR monitors (Gamelin et al., 2006; Parak & Korhonen, 2015; Wallen et al., 2012; Weippert et al., 2010), specifically-designed systems (Cassirame et al., 2013; Parrado et al., 2010), or smart phone applications (Flatt & Esco, 2013) has substantially boosted the use of HRV monitoring in the field. However, despite its common implementation in the field, HRV monitoring is still not accepted as a gold standard, likely due to the lack of consistency in the literature. While some studies have shown that these measures are sensitive to fitness improvements, fatigue, overload or detraining, others have not (Plews et al., 2013). Changes opposite to those expected have also been observed, which further complicates the interpretation of athletes' training status (Plews et al., 2013).

Besides the importance of monitoring HRV in athletes, in recent years, growing interest in understanding the sleep of athletes has seen an increase in published studies (Roberts et al., 2019). In fact, athletes and coaches have ranked sleep as the most important recovery strategy (Fallon, 2007). Interestingly, the fundamental difference between recovery interventions with established protocols (e.g., cold water immersion, compression garments, electrical stimulation) (Nedelec et al., 2013) and sleeping lies in the fact that sleep initiation does not depend entirely on the willingness of the athlete (Nedelec et al., 2015a).

During sleep, anabolic metabolism is upregulated (Chennaoui et al., 2016), procedural memories are consolidated (Frank & Benington, 2006), and immune responses are augmented (Besedovsky et al., 2012). However, sleep loss or deprivation can have significant effects on performance, motivation, perception of effort, and cognition as well as numerous other biological functions (Halson, 2014b). Furthermore, sleep is associated with many physiological processes that may facilitate recovery from, and adaptation to, athletic training and competition (Samuels, 2008). Thus, the ability to monitor the sleep duration and quality of sleep obtained by an (elite) athlete may be a useful tool for evaluating recovery from training and competition (Sargent et al., 2016). However, little is known about the sleep characteristics of athletes (Halson, 2014b; Sargent et al., 2014a), especially female (Roberts et al., 2019). This appears to be a considerable oversight given that sleep has been recognized as an essential component of recovery. Therefore, it is important to understand how the demands of training and competition affect sleep, and this has become a priority for coaches and scientists monitoring athletes (Gupta et al., 2017).

1.4.1. Autonomic cardiac function and sleep patterns in soccer

During congested competitive periods, soccer players follow strict match and training schedules which can reduce sleep duration (Sargent et al., 2014b) and impair recovery processes (Fullagar et al., 2016a), especially when training sessions and/or matches occur close to bedtime sleep (Fullagar et al., 2016a; Vitale et al., 2019).

The effects of physical exercise on sleep have been ascribed to factors such as time of day, chronotype (i.e., an individual's circadian rhythm) (Bonato et al., 2017), and training load (Buchheit et al., 2004). Bonato et al. (2017) evaluated whether the time of day (8.00 a.m. vs 8.00 p.m.) and chronotype could influence post-exercise autonomic cardiac control in soccer players in relation to an acute session of high-intensity interval training. The authors showed that circadian typology determined different autonomic responses during recovery from a demanding training bout only in the morning. In a review study, it was suggested that sleep indices were likely dependent on the scheduling of practices of the

particular sport (Juliff et al., 2015). The study also stated that 52 % of elite athletes subjectively reported sleep disturbances following a late match or training session. Additionally, it was observed that players presented sleep duration within the appropriate healthy range on training and match days concluded before 6 p.m., but slept significantly less with later bed times after training sessions and matches starting after 6 p.m (Fullagar et al., 2016a; Nédélec et al., 2019). However, in another study it was found that total sleep time was not affected after performing early evening high-intensity training sessions (starting at ~4.30 p.m. and finishing at 6.30 p.m.) in elite youth soccer players, compared to nights where no evening training was performed (Robey et al., 2014). Therefore, further research is needed to determine whether regular training scheduled in the late evening affects sleep patterns in team sport athletes. Other factors could also impair the function of the ANS and sleep, such as travelling and away-match location (Egan-Shuttler et al., 2018). However, the interaction between these factors with nocturnal HRV and sleep patterns (evaluated simultaneously) has not yet been investigated, especially in female soccer players.

Nonetheless, it is also important to highlight that sleep patterns and HRV changes that may occur during sleep after physical exercise can be influenced by whether the athletes are exposed to chronic (habitual) or acute (single) late training (Rae et al., 2015) or a night official competition (Vitale et al., 2019). For instance, in a recent study was showed that sleep duration and quality of female and male athletes were acutely lower during the night immediately after a night-match compared to previous or subsequent nights (Vitale et al., 2019). In addition, in another study was showed that acute physical exercise (running exercises), in physically active male subjects, caused delayed recovery of nocturnal cardiac autonomic modulation, but no changes in sleep quality (Myllymaki et al., 2012).

For instance, Rae et al. (2015) proposed comparing morning and evening time-trial performance, RPE, and mood states of trained swimmers, considering chronotype and habitual training time-of-day. The authors found significant diurnal variation in performance when the swimmers were grouped according to habitual training time-of-day. That is, the swimmers who habitually trained in the

morning swam faster at 6.30 a.m. and those who trained in the evening were faster at 6.30 p.m. This suggests that diurnal variation in performance is also related to habitual training time, although it is not clear whether this is due to endogenous factors, training time conditioning, or both.

In summary, it is noteworthy that more studies is needed in the literature analysing objective sleep variables and HRV indices (simultaneously) across multiple night-training days, match days, and rest days, as well in different match locations (i.e., away-matches vs. home-matches) in high-level female soccer players, over several weeks (chronic responses) during the competitive in-season. Therefore, we conducted two observational studies to describe and characterize sleep patterns and nocturnal HRV in high-level female soccer players under different match and training constraints.

One observational study (Study 2) had the main purpose of analyzing whether exercise training conducted at night disturbed sleep and affected nocturnal cardiac autonomic control during three consecutive weeks (16 days of recordings) of the competitive season. The second observational/longitudinal study (Study 3) had the main objective of analysing the influence of the timing of training and matches, and match location, on the same variables, for six weeks (42 days of recordings) of the competitive season. This knowledge could provide information on training programming in order to optimize recovery by means of implementing sleep hygiene strategies to extend sleep or planning day-time naps (Fullagar et al., 2015a).

1.4.2. Nocturnal measurements

Measuring pulse rate is handy and straightforward. It can be measured on different settings (i.e., during sleep or awake at rest, during or following exercise), and its analysis can be simple or complex (e.g., HR values vs. HRV). All recording conditions and methods of analysis have advantages and disadvantages, which need to be understood when selecting the most appropriate monitoring methodology for athletes (Buchheit, 2014).

The physiological determinants of resting HRV are multiple and include cardiac muscle morphology, plasma volume, autonomic activity, age and body

position; resting HRV is essentially related to genetics, plasma volume, autonomic activity, and body position (Achten & Jeukendrup, 2003; Aubert et al., 2003; Bosquet et al., 2008; Sandercock & Brodie, 2006). The basic principle of HRV monitoring is to make inferences on possible changes in cardiac ANS status due to exercise while using repeated HRV measures over time. Since ANS activity is highly sensitive to environmental conditions (e.g., noise, light, temperature) (Achten & Jeukendrup, 2003), it is important that precautions be taken to standardize recording conditions, in order to isolate the training-induced effects on ANS.

Theoretically, night recordings represent the best (more standardized) recording condition for HRV monitoring (Brandenberger et al., 2005; Pichot et al., 2000). However, the effects that differences in sleep patterns (Otzenberger et al., 1998) and quality (Burton et al., 2010) have on HRV, independently of training-related changes in ANS status, have been overlooked in the literature, and consequently lead to misinterpretation. To overcome these limitations, HRV data collected during selected slow-wave sleep episodes (SWSE; defined as deep stage of sleep), that offers great signal stability and high standardization of both environmental factors and respiratory influences on HRV, might be preferred (Brandenberger et al., 2005; Buchheit et al., 2004). Nevertheless, night recordings could be difficult to implement daily (Stanley et al., 2013b), limiting their usefulness.

One of the most critical aspects of the recovery *continuum* for athletes is obtaining enough sleep duration and quality of sleep. It is recommended that adults sleep at least 7 hours per night and achieve a sleep efficiency (i.e., time asleep as a percentage of time in bed) of at least ≥ 75 % on a regular basis to promote health (Ohayon et al., 2017; Watson et al., 2015). However, athletes usually sleep less than 7 hours (Gupta et al., 2017), requiring more accumulated time to sleep. In fact, extended sleep duration can lead to better psychomotor accomplishment and technical accuracy (Mah et al., 2011), with likely positive effects on competitive performance (Kolling et al., 2016b). Interestingly, most of the research examining athletes' sleep has been derived from subjective tools (e.g., diaries) (Knufinke et al., 2018). This is a problem because subjective tools,

while useful for monitoring large cohorts, typically correlate poorly with objective data (Dunican et al., 2017).

The ‘gold standard’ for sleep monitoring is polysomnography (PSG), which uses surface electrodes to monitor physiological parameters such as brain, muscle, heart, and respiratory activity (Kushida et al., 2005). PSG is particularly useful for investigating sleep pathologies, including sleep-disordered breathing (George et al., 2003) and sleep disturbances caused by concussion (Gosselin et al., 2009). However, PSG is expensive and requires specialized laboratory equipment, making it impractical for monitoring athletes in the field (Sargent et al., 2016).

Actigraphy, on the other hand, uses accelerometers embedded in wearable devices to record movements that can be analysed using algorithms that estimate sleep duration and quality (Ancoli-Israel et al., 2003). Actigraphy is inexpensive and can be administered with minimal impact on habitual sleep or training and/or match routines. As such, actigraphy is the preferred method for objectively monitoring during night the sleep of athletes (Sargent et al., 2016).

1.4.2.1. Autonomic cardiac activity

The cardiovascular system is characterized by a complex interaction of several organs and tissues including heart and blood vessels; it is regulated by intrinsic and extrinsic mechanisms (Ferreira & Zanesco, 2016). The ANS provides rapid adjustment of the heart and blood vessels, playing an important role in cardiovascular system regulation.

The heart is a muscular organ with a special excitatory and conduction specialized system able to generate rhythmic electrical impulses, as well as to transmit these signals throughout the myocardium (Ferreira & Zanesco, 2016). Under normal conditions, the conduction process begins in a particular area of the heart, named the atrial sinus node, whose electrical property can generate the action potential that spreads quickly through specialized fibres to the heart, resulting in contraction of the entire cardiac muscle (Shaffer et al., 2014). In addition to this intrinsic mechanism that determines the basal cardiac rhythm, the

ANS plays an important role in controlling the heart function and vascular system through the sympathetic and parasympathetic fibres to the heart, and through the sympathetic fibres to the vessels (Ferreira & Zanesco, 2016).

The two branches of the ANS, i.e. the sympathetic and parasympathetic fibres, act in an opposite way, providing fine adjustment to the cardiac tissues in response to different stimuli and daily activities. Though, an unbalance between sympathetic and parasympathetic drives has been proposed as a potential mechanism in some cardiovascular diseases such as arterial hypertension, heart failure, and myocardial infarct.

1.4.2.1.1. Assessment of autonomic cardiac activity

HRV is widely used as an indirect marker of ANS and the cardiac autonomic nervous system activity. In sports, HRV might provide useful markers of positive and negative adaptations to training and competitions (Halson, 2014b; Plews et al., 2013).

Fluctuations in the R–R (normal-to-normal) intervals may be quantified by numerous techniques, providing indices that reflect the ANS modulation into the heart (Ferreira & Zanesco, 2016). With the objective of standardizing the terms and measurement methods in both basic and clinical studies, members of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology created a Task Force (TaskForce, 1996). Currently, HRV analysis can be performed using linear methods, which are divided into the time domain and the frequency domain, or using non-linear methods.

In the linear analysis in the time domain, which is considered as the simplest measure of HRV, the indices are derived from the measurement of intervals between successive normal beats (R–R) in a series of continuous time that can be evaluated by statistical or geometric patterns (Bilchick & Berger, 2006; TaskForce, 1996).

The analysis in the time domain further provides other related measures, which are derived from the difference between the R–R intervals, including the square root of the mean of the sum of the squares of differences between successive R–R intervals (RMSSD), the standard deviation of the R–R intervals

(SDNN), the number of pairs of adjacent R–R intervals with a difference of duration longer than 50 ms in the registration period (NN50), and the percentage of successive R–R intervals with a difference of duration longer than 50 ms (pNN50) (Ferreira & Zanesco, 2016).

These indices are obtained by the difference between successive regular intervals aiming to detect high frequency oscillations and to provide information on parasympathetic autonomic modulation (Kleiger et al., 2005; Pumprla et al., 2002). Another technique is the Lorenz plot (also known as a Poincaré plot), where each beat is plotted in association with the next beat, providing graphical information and dispersion of the variation in the time series (Ferreira & Zanesco, 2016). This analysis can be performed both quantitatively and qualitatively (Billman, 2013).

The linear method in the frequency domain (spectral analysis) has been widely used since its introduction in the 1960s as another technique for the investigation of HRV (Ferreira & Zanesco, 2016). Unlike the time domain, this technique decomposes the total variability of the signal into specific components that operate in different frequency bands, allowing identification (Shaffer et al., 2014). The calculation of the power of spectral density can be performed through fast Fourier Transform Techniques or the autoregressive model (Ferreira & Zanesco, 2016). As short-time records (2–5 minutes), it is possible to obtain the components of very low frequency (VLF<0.04 Hz), low frequency (LF; 0.04–0.15 Hz), and high frequency (HF; 0.15–0.4 Hz). In the analysis over 24-hours, a fourth peak frequency, represented as ultra-low frequency (ULF; 0.003–0.04 Hz) can also be obtained (Billman, 2013; TaskForce, 1996).

The HF component has been widely emphasized as an index that reflects the vagal modulation, whereas the LF component reflects an interaction between sympathetic and parasympathetic (Kleiger et al., 2005). On the other hand, experimental data suggest that the rhythm pattern of very low frequency is intrinsically generated by the heart and that its oscillation is modulated by sympathetic nerve endings (McCraty & Shaffer, 2015). In addition, the ratio between LF and HF (LF/HF) has been used historically as a measure involving the sympathetic/parasympathetic balance (Pagani et al., 1986). Nevertheless,

recent studies suggest that this measure cannot be used as an accurate measure of this balance (Billman, 2013).

Evaluation of the HRV from linear methods can be performed from records with durations of 2, 5, and 15 minutes (short-time), and over 24-hours (long-time) (Ferreira & Zanesco, 2016). Although it is also used for short-term analysis, the indices obtained in the time domain have been commonly used for long-term records to provide better interpretation of the results, because of the instability of HR over time. On the other hand, short records are preferably interpreted from the frequency domain indices (TaskForce, 1996). The presence of noise, trends, ectopic beats, and artefacts has been considered as the main problem found in records of HRV. These issues can directly affect the quality of HRV analysis, requiring signal correction (Huikuri et al., 1999). Therefore, ectopic beats are, in general, automatically removed and replaced with interpolated adjacent R–R interval values using a low filter (Tarvainen et al., 2014). In addition, to reduce any potential non-uniformity or skewness in HRV, data can be log-transformed by taking the natural logarithm (Ohlsson et al.) before conducting any statistical analyses (Mourot et al., 2004).

Monitoring training-related cardiac autonomic responses has been facilitated by using after-waking ultra-short-term HRV measurements in male and female athletes (Esco et al., 2016; Fazackerley et al., 2019; Flatt et al., 2017a; Flatt et al., 2017b; Stanley et al., 2013b). In spite of its usefulness, this method does not allow analysis of the time course of post-exercise cardiac autonomic recovery or quantification of HRV during periods of physiological steady state (Al Haddad et al., 2009; Boullosa et al., 2013). In this sense, HRV recordings conducted during night sleep could be an interesting alternative, as previously mentioned in this chapter.

In fact, in one study overnight HRV indices (i.e., increased low frequency [LF, in ms^2] and reduced high frequency [HF, in ms^2]) were significantly altered after competitive matches compared to rest days (Bricout et al., 2010). However, most studies involving overnight HRV analysis do not detail the standardization of the data acquisition and interpretation, a crucial step to allow comparison of results obtained in different studies.

In this regard, we searched through the literature describing methods of overnight HRV analysis to allow the replication of the procedures (Study 1). Thus, SWSE (Al Haddad et al., 2009; Brandenberger et al., 2005; Buchheit et al., 2004) was one of the methods chosen to assess HRV in our studies. The SWSE considers the following:

1) the first 10 min of the first low and regular HR episode lasting at least 15 min;
2) the lowest standard deviation of R–R intervals (SDNN) throughout the period of interest;
3) a circular Poincaré plot (i.e., a round cluster of points in R–R intervals plotted as a function of the previous one);
4) a low inter-beat autocorrelation between successive R–R intervals (i.e., correlation coefficient of the Poincaré plot < 0.5).

Using the SWSE, it was observed that a single session of supramaximal intermittent exercise caused a reduction in vagally-mediated HRV indices among young non-athletes during night sleep following exercise (Al Haddad et al., 2009). It is important to highlight that the SWSE requires the analysis of “only” 10 min out of many hours of sleep.

In contrast, has been proposed the analyses of overnight sleep cardiac autonomic activity using an “hour-by-hour” approach using all the R–R intervals recorded throughout the sleep period (Myllymaki et al., 2011). The authors found that vigorous late-night exercise did not disturb sleep quality in physically active male subjects (Myllymaki et al., 2011). However, it affected the cardiac autonomic control during the first sleeping hours. To date, no studies had concurrently analysed the sensitivity of both methods (SWSE or “hour-by-hour”) in detecting the effects of acute training sessions in highly trained female athletes, with special reference to assessing the autonomic activity following late-night team sports training. Therefore, one of the main objectives of the present thesis was to assess the sensitivity of different methods to assess nocturnal HRV after soccer night-training sessions in high-level female athletes (Study 1). We also aimed to analyse whether the timing of training (i.e., at night), rest days, match days and

match location may affect nocturnal cardiac autonomic activity, during the competitive season, in female players (Studies 1, 2, and 3).

1.4.2.2. Sleep patterns

In general, sleep is a basic requirement to preserve human health; it is assumed to be critical to physiological and psychological restoration in athletes (Leeder et al., 2012). Recent studies have analysed the importance of sleep to regulate key molecular mechanisms (i.e., transcriptional regulatory proteins (Abel et al., 2013; Allada & Siegel, 2008; Crocker & Sehgal, 2010)), demonstrating that sleep has an integral role in metabolic homeostasis (Xie et al., 2013). Notwithstanding the complexity surrounding the need, rationale, and outcome of sleep, it seemingly must serve an important purpose for humans, because sleep has survived so many years of evolution (Sehgal & Mignot, 2011). The ability of humans to cope with physiological and psychological stressors is critical to athletic performance outcomes (Bishop, 2008), and is affected by numerous factors, including experience, fitness, motivation, and the natural fluctuation of physiological and behavioural processes across a 24-h period (i.e., sleep–wake cycle, body temperature, hormone regulation) (Drust et al., 2005).

Circadian rhythms are primarily controlled by the suprachiasmatic nucleus within the hypothalamus (Beersma & Gordijn, 2007). However, the suprachiasmatic nucleus is unable to always maintain control over these patterns (i.e., between the suprachiasmatic nucleus within the hypothalamus), as humans are highly sensitive to alterations in their natural environment (Beersma & Gordijn, 2007; Fullagar et al., 2015b), most notably through the light–dark cycle (Czeisler et al., 1986). When athletes encounter disruptions to their environments (e.g., travel or training and/or competing at night), endogenous circadian rhythms and normal sleep–wake cycles can become desynchronized (Beersma & Gordijn, 2007; Reilly & Edwards, 2007). These perturbations in sleeping patterns can cause an increase in homeostatic pressure and affect emotional regulation, core temperature, and circulating levels of melatonin, causing a delay in sleep onset (Lack & Wright, 2007).

Additionally, there is potential for sleep loss and neurocognitive and physiological performance to be compromised (Banks & Dinges, 2007; Goel et al., 2009; Halson, 2008; Samuels, 2008). Emerging research suggests that there are differences in sleep duration and quality between athletes and healthy controls. In contrast to non-athletes, athletes are often exposed to conditions that can interfere with sleep duration and quality, such as jet lag, unfamiliar sleeping environments, evening training, and/or competition and underlying fatigue (Robey et al., 2014).

1.4.2.2.1. Assessment of sleep patterns

To detect and manage sleep disturbances, it is important to monitor habits and perceptions of sleep with subjective and/or objective measures (Myllymaki et al., 2011).

Overall, two methods are primarily utilized to assess sleep: PSG and actigraphy (Nedelec et al., 2015a).

PSG is considered by many to be the gold standard for measuring sleep and typically includes an assessment of eye movement, brain activity, HR, muscle activity, oxygen saturation, breathing rate and body movement (Roomkham et al., 2018). PSG allows for the determination of sleep stages (rapid eye movement and non-rapid eye movement). PSG is typically only utilised to assess specific sleep disorders as it is an expensive, obtrusive and complex technique, requiring expertise in setting up the individual to be monitored and manually scoring the sleep data. Further, PSG typically occurs in a laboratory and therefore is impractical for longitudinal monitoring. Finally, PSG may be useful in a research context where understanding the effects of an intervention on sleep staging may be of interest.

Actigraphy is usually measured by a small wrist device worn on the non-dominant arm (Sargent et al., 2016). According to Gogenur (2010), wrist movements are continuously translated into an electronic signal through the displacement of a piezoelectric transducer. Thereby, the signal is recorded when movement occurs in all three dimensions, and thus distinguishes between “motionless/resting” and “lying” (Peterson et al., 2012). Activity counts are then

provided on a minute-by-minute basis, for example by the so-called zero-crossing mode (Gogenur et al., 2009a; Gogenur et al., 2009b). In the zero-crossing mode, the number of times per minute where the activity crosses zero activity is registered (Gogenur, 2010). These data are then downloaded to a software where the final data analysis is performed. Additionally, data collection starts only when the device is worn on the body and terminates autonomously when off the body (Kolling et al., 2016a).

Various actigraphic devices have already been applied in sport settings to monitor sleep parameters (Fietze et al., 2009; Hausswirth et al., 2014; Mah et al., 2011). Several studies have assessed the validity of activity monitors for measuring sleep by comparing sleep/wake durations determined by PSG with sleep/wake durations determined by activity monitors. In healthy adults, high correlations have been reported for sleep duration (i.e., 0.89–0.98) (de Souza et al., 2003; Kripke et al., 1978; Signal et al., 2005) and moderate-to-high correlations have been reported for wake time within sleep (i.e., 0.36–0.85) (de Souza et al., 2003; Kripke et al., 1978; Mullaney et al., 1980). More recently, validation of activity monitors has moved beyond comparing sleep/wake durations towards considering epoch-for-epoch matches with PSG. Agreement between PSG and activity monitors is high, with rates ranging from 77 to 91 % (Kosmadopoulos et al., 2014; Paquet et al., 2007; Signal et al., 2005).

Overall, wrist-worn accelerometers allow estimation of total sleep time (total amount of sleep obtained), time in bed (time between lying down until getting up the next day), wake up time (time between the last minute of sleep and getting up from bed), sleep onset time (time of the first epoch of sleep between time of trying to initiate sleep and time at wake up), wake after sleep onset (number of min awake after sleep onset), sleep fragmentation index (sum of mobility and immobility accesses in one minute, divided by the number of immobility accesses), latency (time in minutes attempting to fall asleep), and sleep efficiency (percentage of time in bed that was spent asleep) (Sargent et al., 2016). However, activity monitors tend to underestimate sleep in people who exhibit high levels of movement during light sleep (Tryon, 2004). This raises a

potential issue with the use of activity monitors for measuring sleep in (elite) athletes.

Several studies indicate that elite athletes obtain less sleep than the general population (Roach et al., 2013; Sargent et al., 2014a) and/or exhibit greater movement and fragmentation during sleep (Leeder et al., 2012; Taylor et al., 1997). Given the sleep characteristics of elite athletes, it is important to establish how well activity monitors detect sleep and wake variables in this population. Therefore, some specific technical procedures were considered when using 3-axial accelerometers (Actigraph LLC wGT3X-BT, Pensacola, USA) during data collection for the prospective studies conducted for the current thesis. The sampling frequency was selected as 50 Hz and the epoch of activity counts was 60 seconds. All movements greater than 0.05 g were measured, and values outside the range of 3–11 Hz were filtered to eliminate gravitational artefacts (Myllymaki et al., 2011; Paquet et al., 2007). All sleep variables were determined for each night using the *Sadeh* algorithm (validated for young-adults) (Sadeh et al., 1994).

Finally, subjective ratings can be obtained via sleep logs, which provide useful information about the individual's habits and perception of sleep (Baker et al., 1999). Nevertheless, subjective reports might deviate from objective measures (Kawada, 2008), especially with regard to mood and memory biases, while personality characteristics may also affect self-reported sleep ratings (Jackowska et al., 2011). Indeed, some discrepancies have been detected when comparing subjective parameters with objective measures (Kolling et al., 2016a).

1.5. The importance of individualized monitoring

Although it is conventional to focus monitoring on group mean responses following a particular training intervention or competition, sport settings frequently produce mixed results with high responders and low responders often getting lost in averaged data reports (Chrzanowski-Smith et al., 2019; Mann et al., 2014). As a result, an increased interest for individualization of monitoring in sport settings has given rise to a variety of athlete-monitoring strategies, enabling coaches to

better manage fatigue and manipulate training prescription on an individual basis (Halson, 2014a).

Nevertheless, research examining the sleep of athletes has typically averaged data across several nights, providing a mean estimate of usual sleep (Lastella et al., 2015; Leeder et al., 2012; Swinbourne et al., 2016), especially when examining sleep and nocturnal HRV in female soccer players (Studies 1, 2, and 3). While such approaches are useful to allow basic insight into sleep and HRV (to better understand fatigue and recovery in athletes), they lack the sophistication to provide understanding of how sleep and nocturnal HRV may vary across multiple nights at the individual level (Bei et al., 2016; Buchheit, 2014; Nedelec et al., 2018). Moreover, individual variability can reflect differences within individuals over time (Van Dongen, 2005), with high intra-individual variability in the athletes' sleep indicating the need for individualized sleep education strategies and interventions to promote appropriate sleep (Nedelec et al., 2018).

Although identifying the optimal amount of sleep on an individual basis may be difficult (Watson, 2017), adult and youth athletes who demonstrate average sleep of less than 7 or 8 h, respectively, likely warrant additional evaluation to identify their specific sleep barriers. Therefore, those individuals that demonstrate negative effects of insufficient sleep duration should be encouraged to use sleep hygiene techniques to improve daytime energy and alertness (Gupta et al., 2017). Longitudinal monitoring of training and match load, sleep, fatigue (e.g., through HRV), stress, and mood may not only help identify individuals at risk, but also monitor improvements in sleep, well-being, and performance after interventions (Simpson et al., 2017).

In this respect, it might be important to include sleep and nocturnal HRV data encompassing individual responses, in addition to group means (Nedelec et al., 2018). Also, special attention should be given to the sleep behavior of elite athletes (e.g., total sleep time) during periods of congested fixtures, such as international tournaments, since sleep deficits can impair performance (Fullagar et al., 2015b).

Although data exist on the role of sleep in recovery and on the impact of various interventions (e.g., competitions, time of day for training, training and

match loads) on sleep duration and quality, there is a need for more studies to describe individual sleep variability during international tournaments, especially in elite female athletes, since sleep patterns can affect performance outcomes (Juliff et al., 2018). These investigations may identify potential factors related to disturbed sleep and nocturnal HRV, which could assist in recommending appropriate sleep strategies and better managing fatigue, as well as manipulating training prescription and post-match recovery on an individual basis. Therefore, we conducted an observational study (Study 4) with the aim of describing sleeping patterns and nocturnal HRV individual profiles of elite female soccer players from a National team during an international tournament.

Despite the need for individual studies examining recovery status (i.e., sleep and HRV) in athletes, the accurate assessment of an individual's training load is also imperative for effective training prescription. As previously mentioned, (*see 1.3. Monitoring training and match load*), training load can be quantified by recording both the internal and external loads imposed upon the individual player (Impellizzeri et al., 2004). Therefore, valid and reliable indicators of training load are essential to monitor the training process. However, it is also important in longitudinal studies to quantify intra-individual responses (e.g., within-participant associations) following the most appropriate statistical approach, which models the longitudinal dataset as a whole using the correct degrees of freedom (Atkinson et al., 2011; Bland & Altman, 1995; Chrzanowski-Smith et al., 2019; Lazic, 2010). For example, a high within-participant correlation was reported between s-RPE and TRIMP for estimating training load in elite male soccer players across a typical in-season competitive phase (Kelly et al., 2016), suggesting that s-RPE is a simple and practical global indicator of individual training load in elite-level soccer players and can reflect the internal training load stressors elicited on individual players. Nonetheless, this finding needs to be confirmed in other populations (e.g., female soccer players).

With this in mind, we conducted an observational study (Study 5) not only to investigate the association (within-participant correlation) between s-RPE and TRIMP, using training sessions with similar contents (i.e., technical training with ball involvement) and duration, but also to verify whether different ranges of

relative heart rates would correspond to each RPE category. Also, we examined the amount of time spent in relative high intensities and the associated intra- and inter-player variability during technical training sessions in high-level female soccer players.

1.6. Recovery strategies: sleep hygiene

The term ‘sleep hygiene’ was first used by Hauri (1977) in the context of providing recommendations for patients to help them improve their insomnia. Primary sleep hygiene strategies originally addressed caffeine, alcohol, and exercise; they were derived from scientific studies and/or clinical observations of patients with poor sleep (Stepanski & Wyatt, 2003). Nevertheless, given the significant implications for performance, health, and general well-being, a number of recommendations have been suggested to monitor and improve sleep in athletes (Fullagar et al., 2015b; Simpson et al., 2017; Taylor et al., 2016).

In soccer, sleep impairment may be acutely dictated by some constraints, such as playing or training at night close to bedtime, congested scheduling, travelling, light exposure, use of products containing caffeine or alcohol in the period preceding bedtime, and variations in wake up time or bedtime (Nedelec et al., 2015a). Thus, proper sleep hygiene is important for all athletes, including sleep environment and sleep scheduling. Sleep environments should be comfortable, cool, dark, without electronic devices, and with minimal ambient noise or distraction (Watson, 2017). To the extent that training and competition schedules allow, athletes should be encouraged to establish consistent sleep and wake times and incorporate a 30- to 60-min period of quiet relaxation before bedtime that can help facilitate sleep onset (Watson, 2017). Efforts should be made to limit the effects of training and competition on sleep schedules to reduce the risk of sleep restriction in athletes. Variation in training times should be minimized and early morning and late evening training and competitions should be avoided (Nedelec et al., 2015a).

One possible way to examine the effect of sleep on performance is to extend the amount of sleep an athlete receives and determine the effects on subsequent performance. For instance, Mah et al. (2011) instructed six basketball players to

obtain as much extra sleep as possible following two weeks of normal sleep habits. Faster sprint times and increased free-throw accuracy were observed at the end of the sleep extension period. Mood was also significantly improved, with increased vigour and decreased fatigue (Mah et al., 2011). Thus, and according to the data from this study (Mah et al., 2011) suggest that increasing the amount of sleep an athlete receives may significantly enhance performance.

Athletes suffering from some degree of sleep loss may also benefit from a brief nap, particularly if a training session is to be performed in the afternoon or evening. Waterhouse et al. (2007) investigated the effects of a lunchtime nap on sprint performance following partial sleep deprivation (4 h of sleep). Following a 30-min nap, 20-m sprint performance was increased (compared to no nap), alertness was increased, and sleepiness was decreased. In terms of cognitive performance, sleep supplementation in the form of napping has been shown to have a positive influence on cognitive tasks (Postolache et al., 2005). Naps can markedly reduce sleepiness and can be beneficial when learning skills, strategy, or tactics are demanded in sleep-deprived individuals (Postolache et al., 2005). Napping may be beneficial for athletes who have to routinely wake up early for training or competition and for athletes who are experiencing sleep deprivation (Waterhouse et al., 2007). Furthermore, naps may provide an additional performance benefit during periods of unavoidable sleep restriction (Brooks & Lack, 2006). Naps should be relatively brief (~30 min) to prevent sleep inertia and avoided late in the day to prevent any disruption of night-time sleep (Watson, 2017). While further research is needed to clarify the role of naps in athletic performance, specifically in female soccer, the available evidence suggests that naps could be a useful way to increase total sleep duration during periods when sleep restriction is unavoidable, but not necessarily as a substitute for night-time sleep.

It is important to highlight that other types of sleep hygiene strategies exist, especially used in elite soccer players, such as red-light therapy (body receiving irradiation from a red-light therapy instrument), relaxation and brainwave entrainment (involves stimulating the brain during sleep with frequencies between 1 and 9 Hz in a sequence mimicking the healthy human sleep cycle), and sleep

medication (includes hypnotics, medium half-life benzodiazepines [e.g., temazepam], and short half-life non-benzodiazepine medications [e.g., zolpidem]. These medications do not contravene the World Anti-Doping Agency rules (Nedelec et al., 2015a).

In summary, sleep is extremely important for numerous biological functions and sleep deprivation can have significant effects on athletic performance, especially sub-maximal, prolonged exercise. From the available evidence, it appears that athletes may be obtaining less than 8 h of sleep per night and that increasing sleep (sleep extension) or napping may be useful to increase the total number of hours of sleep and thereby enhance performance.

1.7. Rationale and significance of the thesis

Athletes, coaches, and supporting staff should adopt a scientific approach to both designing and monitoring training programs. Appropriate load monitoring is crucial for determine whether a player is adapting to a training program, and minimizing the risk of developing non-functional overreaching, illness, or injury. To gain understanding of the training and match demands and their effects on the player, several potential markers are available. However, very few of them have strong scientific evidence supporting their use. Moreover, very limited data exist in female soccer players.

Monitoring sleep and HRV in athletes can be useful for early detection and intervention before significant performance and health decrements are observed. Non-invasive and time-efficient methods/equipment such as wearable actigraphy and beat-to-beat HR monitors can provide detailed information about positive and negative adaptions over short and long periods throughout the competitive season. In addition, each athlete can perform the recordings at home, adopting a “real world scenario” to grant high ecological validity to the research and/or practical interventions. The accumulated knowledge regarding the importance of sleep and HRV (especially during night sleep) has led sleep and HRV monitoring to become a popular strategy among elite athletes, coaches, and supporting staff. However, given the complexity of analyzing nocturnal measurements of sleep patterns and cardiac autonomic activity and the limited availability of athletes to

participate in sleep studies, those indicators are poorly documented, especially in female athletes.

Monitoring training and match load is also crucial to understand responses to training and readiness, enabling appropriate planning. Importantly, load monitoring also intends to reduce the risk of injury, illness, and non-functional overreaching. In addition, training load data may be useful for team selection and determining which athletes are ready to sustain competition demands.

Therefore, our observational studies on sleep and HRV of elite and semi-professional female soccer players could assist coaches and clinical practitioners to identify sleep and HRV disturbances, especially during periods of high congested fixtures such as international tournaments. This may also be relevant since in some countries (e.g., Portugal), the majority of female soccer teams usually start training sessions at very late hours, close to bedtime sleep, due to their life commitments (e.g., job, university) which need to be reconciled with training schedules. Finally, the present thesis highlights the substantial individual variation in training and match load, sleep, and HRV, which counsels the adoption of an individual approach to training and match load monitoring, in designing sleep education strategies (sleep hygiene) and interventions to promote appropriate sleep and recovery, not only in female soccer, but also in other sport populations (e.g., academies or high performance centres of youth and adults athletes).

Chapter II

Aims and Structure

2. Aims

The present thesis aims to investigate the impact of training sessions and matches performed at different times of the day and in different locations on autonomic cardiac function and sleep patterns of female soccer players from different competitive levels (elite and semi-professional), during competitive in-season and during an international tournament.

All study designs were carefully explained to the subjects, and written informed consent was obtained. The following exclusion criteria were defined: age ≥18, tobacco use, and use of medications and medical conditions contraindicating physical exercise as diagnosed by a sports medicine physician. Players were requested to avoid alcohol and caffeine consumption. All studies followed the Declaration of Helsinki and were approved by the Ethics Committee of the Faculty of Sports, University of Porto (CEFADE 03.2017).

Studies 1, 2, 3 and 5 were conducted with the same semi-professional female soccer team, competing in the first division of the Portuguese soccer league. Study 4 was conducted with the Portuguese National female soccer team during an international tournament (Algarve Cup 2018). All studies are described in detail in chapter III.

3. Structure of the thesis

The present dissertation is organized into four chapters. A survey of the literature supporting the aims of the dissertation is provided in Chapter I. The main aim of the thesis and the purposes of each study are outlined in Chapter II. The studies conducted within the purpose of the thesis are presented in Chapter III. Overall, a total of 5 original studies were conducted, each attempting to address specific research questions. Additional research outputs are included in the Appendix section. General discussions, limitations, conclusions, practical applications, and future research suggestions of the present thesis are outlined in Chapter IV.

4. List of original studies

Study 1

Effects of Late-Night Training on "Slow-Wave Sleep Episode" and Hour-by-Hour-Derived Nocturnal Cardiac Autonomic Activity in Female Soccer Players.

Purpose: To assess the sensitivity of nocturnal HRV monitoring methods to the effects of late-night soccer training sessions in female athletes.
Hypothesis: It was hypothesized that training at night compared to non-training days would lead to disturbances in both nocturnal cardiac autonomic activity methods in female soccer players.
Methods: Eleven female soccer players competing in the first division of the Portuguese soccer league wore HR monitors during sleep at night throughout a 1-week competitive in-season microcycle, after late-night training sessions (n = 3) and rest days (n = 3). HRV was analysed through SWSE (10-min duration) and "hour by hour" (all the R–R intervals recorded throughout the hours of sleep). Training load was quantified by s-RPE (281.8 [117.9] to 369.0 [111.7] arbitrary units [AU]) and TRIMP (77.5 [36.5] to 110.8 [31.6] AU), and added to subjective well-being ratings (Hopper index = 11.6 [4.4] to 12.8 [3.2] AU). These variables were compared between training and rest days using repeated-measures analysis of variance.
Results: The log-transformed SWSE cardiac autonomic activity (lnRMSSD varying between 3.92 [0.57] and 4.20 [0.60] ms; η^2p = 0.16; 95 % confidence interval, .01–.26), lnHF , lnLF, lnSD1 (natural logarithm of short-term beat-to-beat variability), and lnSD2 (natural logarithm of long-term beat-to-beat variability), and the non-transformed LF/HF were not different between night-training session days and rest days (P > 0.05). Considering the hour-by-hour method (lnRMSSD varying between 4.05 [0.35] and 4.33 [0.32] ms; η^2p = 0.46; 95 % confidence interval, 0.26–0.52), lnHF, lnLF, lnSD1, lnSD2, and the non-transformed LF/HF were not different between night-training session days and rest days (P > 0.05).
Conclusion: Late-night soccer training does not seem to affect nocturnal SWSE and hour-by-hour HRV indices in highly trained athletes.

Study 2

Does Night Training Load Affect Sleep Patterns and Nocturnal Cardiac Autonomic Activity in High-Level Female Soccer Players?

Purpose: To analyse whether exercise training conducted at night disturbs sleep and affects nocturnal cardiac autonomic control in high-level female athletes.

Hypothesis: It was hypothesized that sleep patterns and/or autonomic cardiac activity would be affected by night-training sessions in high-level female athletes, when compared with rest days.

Methods: A total of 18 high-level female soccer players (mean [SD]: age 20.4 [2.1] y) wore actigraph units and HR monitors during night sleep throughout night training days (n = 8) and rest days (n = 8), for 3 consecutive weeks. This was a longitudinal study that measured internal training load, sleep, nocturnal cardiac autonomic activity, and well-being ratings prior to training sessions.

Results: Training load varied across training days (e.g., TRIMP range, mean [SD]; effect size, ES [95 % confidence interval]: 72.9 [18.8] to 138.4 [29.6] a.u.; $F_{4,62}$ = 32.331; η^2p = 0.673 [0.001–0.16], large effect; P < 0.001). However, no differences in subjective well-being ratings were observed, although *ES* was large. Total sleep time (training days vs rest days: 07:17 [00:47] h vs 07:51 [00:42] h; *ES* = 0.742 [0.59–0.92], P = 0.005; moderate effect) and sleep onset time (00:58 [00:19] h vs 00:44 [00:16] h; *ES* = 0.802 [0.68–0.94], P = 0.001; moderate effect) were negatively affected after night training. In addition, small effects were detected for wake-up time, time in bed, and sleep latency (P > 0.05). No differences were detected in HRV during sleep (range of lnRMSSD: 4.3 [0.4] to 4.5 [0.4] ln[ms] vs 4.6 [0.3] to 4.5 [0.4] ln[ms]; $F_{3,52}$ = 2.148; P > 0.05; η^2p = 0.112 [0.01–0.25], medium effect), but the HR during sleep was significantly higher after training days (range of HR: 56 [4] to 63 [7] bpm vs 54 [4] to 57 [6] bpm; $F_{2,32}$ = 15.956; P < 0.001; η^2p = 0.484 [0.20–0.63], large effect).

Conclusion: Overall, the results indicate that exercise training conducted at night may disturb sleep and affect HR, whereas limited effects can be expected in HRV assessed during sleep in high-level female soccer players.

Study 3

Sleep patterns and nocturnal cardiac autonomic activity in female athletes are affected by the timing of exercise and match location.

Purpose: The aim of the current study was to analyse the influence of the timing of training sessions and matches, and match location, on sleep pattern and nocturnal cardiac autonomic activity in female soccer players.

Hypothesis: It was hypothesized that training at night and playing away-matches would disturb sleep patterns and nocturnal cardiac autonomic activity more than rest days and playing home-matches, respectively, in female soccer players.

Methods: A total of 17 female soccer players (age: 21.6 ± 2.3 years; mean ± SD) wore wrist actigraph units and HR monitors during night-sleep throughout 18 night-training days, 18 rest days, and 6 match days (3 away-matches and 3 home-matches) of the competitive period. Training load was quantified by s-RPE, HR, TRIMP, and subjective well-being.

Results: In night-training days, sleep onset time and total sleep time were significantly impaired compared to match days (+ 1:47 [0:48; 1:55] hours and −1:35 [-1:42; -0:57] hours, respectively; $p < 0.001$; mean difference ± 95 % confidence interval [CI]) and rest days (+ 1:31 [0:52; 1:49] hours and -1:26 [-1:28; -0:55] hours, respectively; $p < 0.001$). In away-matches, sleep onset time was delayed compared to home-matches (+ 0:36 [0:12; 0:44] hours; $p < 0.001$). Sleep latency was higher in night-training days compared to rest days (+ 4 [2; 5] min; $p<0.001$), as well as after away-matches compared to home-matches (+ 5 [1; 7] min; $p < 0.001$). HR during sleep was significantly increased after night-training days and match days compared to rest days (+ 4 [1; 5] bpm and + 3 [1; 4] bpm, respectively; $p < 0.001$). Furthermore, HRV decreased after night-training days and match days compared to rest days (e.g., lnRMSSD, -0.09 [-0.18; -0.08] ln[ms] and -0.17 [-0.27; -0.11] ln[ms], respectively; $p < 0.001$).

Conclusions: Overall, the time of day for soccer practice (i.e., training at night) and match location (i.e., away-matches) may cause disruption in sleep patterns and/or autonomic cardiac activity in female soccer players. Additionally, playing

official matches during the day and training at night may affect nocturnal cardiac autonomic activity by decreasing vagal-related modulation and increasing HR during sleep.

Study 4

Intra-individual variability of sleep and nocturnal cardiac autonomic activity in elite female soccer players during an international tournament.

Purpose: To describe individual sleeping patterns and nocturnal cardiac autonomic activity of National team female soccer players during an international tournament.

Hypothesis: It was hypothesized that this investigation may find substantial individual variability in sleep and HRV measures, which could assist in better defining and recommending appropriate sleep hygiene strategies as well as more adequately managing fatigue, and manipulating training prescription and post-match recovery on an individual basis.

Materials and methods: Twenty elite female soccer players (aged 25.2 ± 3.1 years) wore wrist actigraph units and HR monitors during night-sleep throughout 9 consecutive days (6 day-time training sessions, 2 day-time matches and 1 evening time match) of an international tournament. Training and match loads were monitored using the s-RPE and wearable 10-Hz global positioning system (total distance covered, training and match exposure time, and high-speed running) to characterize training and match loads.

Results: Individually, s-RPE, total distance, exposure time, and high-speed running during training sessions ranged from 20 to 680 arbitrary units (AU), 892 to 5176 m, 20 to 76 min, and 80 to 1140 m, respectively. During matches, s-RPE, total distance, exposure time, and high-speed running ranged from 149 to 876 AU, 2236 to 11210 m, 20 to 98 min, and 629 to 3213 m, respectively. Individually, players slept less than recommended (< 7 hours) on several days of the tournament, especially after evening time match (n=8; TST ranging between 6:00–6:54 h). Total sleep time coefficient of variation ranged between 3.1 and 18.7 %. However, all players presented good sleep quality (i.e., sleep efficiency

≥ 75 %; individual range between: 75–98 %) for each day of the tournament. Most of the players presented small fluctuations in nocturnal cardiac autonomic activity (individual nocturnal HRV ranged between 3.91–5.37 ms and HRV CV ranged between 2.8–9.0 %), while two players presented higher HRV CV (11.5 and 11.7 %; respectively).

Conclusion: Overall, this study highlights the substantial individual variability in sleep and HRV measures, suggesting the adoption of an individual approach to analyse sleep, training and match loads, and recovery, to better understand how players cope with highly demanding competitions.

Study 5

Using the rating of perceived exertion and heart rate to quantify training intensity in female soccer players: validity and utility.

Purpose: The aims of this study were: (1) to analyse associations between s-RPE and TRIMP; to verify whether significantly different ranges of percentage of HR peak (% HR_{peak}) would be reached in each discrete RPE category; and (3) to investigate the amount of time spent > 90 % of HR_{peak} and associated intra- and inter-player variability during soccer technical training sessions with similar content and duration.

Hypothesis: It was hypothesized that an association (within-participant correlation) would be found between s-RPE and TRIMP in high-level female soccer players, using training sessions with similar content (i.e., technical training with ball involvement) and duration. We also hypothesized that significantly different ranges of % HR_{peak} would be reached in each RPE category; this comparison will allow testing of whether RPE category (i.e., exercise intensity) can discriminate different cardiovascular demands during soccer drills even after disregarding training volume (i.e., duration). Finally, we also hypothesized that an association would be found between the amount of time spent > 90 % of HR_{peak} and intra- and inter-player variability during technical training sessions in female soccer; this could be important for coaches and technical staff to better adjust training loads and strategies (i.e., adapt and manipulate some types of

exercises) to adequately stimulate the cardiorespiratory responses of all players and avoid under loading some players while excessively loading others.

Materials and methods: This was a single-group observational study that measured internal training load during six weeks of the competitive period in seventeen high-level female soccer players. All training sessions started around 9 p.m. and lasted on average 94 ± 5 min. During each training session RPE category, s-RPE, TRIMP, HR_{ex} (% HR_{peak}), and time spent at > 90 % of HR_{peak} were assessed.

Results: A very large correlation was found between s-RPE and TRIMP (r = 0.78; 95 % confidence interval: [0.74–0.82]). Significant differences were observed between % HR_{peak} associated with each RPE value (i.e., RPE = 2 AU [68 %; 65–69 % of % HR_{peak}]; RPE 3 [72 %; 69–75 %]; RPE 4 [79 %; 76–82 %]; RPE 5 [84 %; 81 %–87 %]; X^2 =73.34; df = 3; P < 0.001). Intra-and inter-player coefficients of variation for the time spent > 90 % of HR_{peak} (~8 % of training time, ~7 min per session) during training sessions were 73 % and 92 %, respectively.

Conclusion: In conclusion, it was confirmed that s-RPE and TRIMP, displayed good convergent validity and different values of % HR_{peak} were observed for each discrete RPE. However, due to the high variability in the time > 90 % of HR_{peak}, careful monitoring of individual exercises should be performed to ensure the desired training stimulus for each player.

Chapter III

Original studies

Study 1

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- Participation in the scientific meeting with oral communication presentation at the *4th Saúde Atlântica & ISAKOS & ESSKA International Meeting* 2017. Porto, Portugal.
- Participation in the scientific meeting with oral communication presentation at *International Congress on Team Sports* 2018 and published in Abstract book *VI*, pp 52. Universidad Pablo de Olavide, Sevilla, Spain. ISBN: 978-84-617-9806-3

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Human Kinetics
ORIGINAL INVESTIGATION

Effects of Late-Night Training on "Slow-Wave Sleep Episode" and Hour-by-Hour-Derived Nocturnal Cardiac Autonomic Activity in Female Soccer Players

Júlio A. Costa, João Brito, Fábio Y. Nakamura, Eduardo M. Oliveira, and António N. Rebelo

Purpose: To assess the sensitivity of nocturnal heart-rate-variability-monitoring methods to the effects of late-night soccer training sessions in female athletes. ***Methods:*** Eleven female soccer players competing in the first division of the Portuguese soccer league wore heart-rate monitors during sleep at night throughout a 1-wk competitive in-season microcycle, after late-night training sessions (n = 3) and rest days (n = 3). Heart rate variability was analyzed through "slow-wave sleep episode" (10-min duration) and "hour by hour" (all the RR intervals recorded throughout the hours of sleep). Training load was quantified by session rating of perceived exertion (281.8 [117.9] to 369.0 [111.7] arbitrary units [a.u.]) and training impulse (77.5 [36.5] to 110.8 [31.6] a.u.), added to subjective well-being ratings (Hopper index = 11.6 [4.4] to 12.8 [3.2] a.u.). These variables were compared between training and rest days using repeated-measures analysis of variance. ***Results:*** The log-transformed slow-wave sleep-episode cardiac autonomic activity (lnRMSSD [natural logarithm of the square root of the mean of the sum of the squares of differences between adjacent normal RR intervals] varying between 3.92 [0.57] and 4.20 [0.60] ms; η_p^2 = .16; 95% confidence interval, .01–.26), lnHF (natural logarithm of high frequency), lnLF (natural logarithm of low frequency), $\ln SD_1$ (natural logarithm of short-term beat-to-beat variability), and $\ln SD_2$ (natural logarithm of long-term beat-to-beat variability), and the nontransformed LF/HF were not different among night-training session days and rest days ($P > .05$). Considering the hour-by-hour method (lnRMSSD varying between 4.05 [0.35] and 4.33 [0.32] ms; η_p^2 = .46; 95% confidence interval, .26–.52), lnHF, lnLF, $\ln SD_1$, and $\ln SD_2$ and the nontransformed LF/HF were not different among night-training session days and rest days ($P > .05$). ***Conclusion:*** Late-night soccer training does not seem to affect nocturnal slow-wave sleep-episode and hour-by-hour heart-rate-variability indices in highly trained athletes.

Keywords: autonomic nervous system, overnight, overload, recovery, supine

Heart rate variability (HRV) comprises quantitative indices of variations between consecutive heartbeats (ie, RR intervals), collected in humans under standardized conditions.[1] For instance, the use of short-term (5 min) or long-term (24 h) RR intervals recordings has been recommended.[1] However, in less controlled but ecologically valid settings (eg, sports settings), HRV has also been shown to provide useful markers of positive and negative adaptations to training.[2,3] In general, an increase in resting vagally mediated HRV indices in response to team sports training underlies positive cardiac autonomic adaptation,[2,4–6] whereas persistent reduction of these indices is associated to fatigue accumulation.[7,8] However, in some cases (eg, endurance sports), the increase in the parasympathetic activity can indicate an excessive overload leading to loss of performance and cardiovascular function (eg, reduction in peak heart rate).[9,10] Therefore, it has been argued that HRV changes need to be put into context by concomitantly assessing perceived changes in training tolerance (using the Daily Analysis of Life Demands for Athletes questionnaire,[11] for example).[10]

It is important to highlight that monitoring training-related cardiac autonomic responses has been facilitated by the use of after waking ultra-short-term HRV measurement.[4,5,7,8] In spite of its usefulness, this method does not allow the analysis of the time course of the cardiac autonomic recovery postexercise or the quantification of HRV during periods of steady physiological state.[12,13] In this sense, HRV recordings made during night sleep can be an interesting alternative.

In fact, Bricout et al[14] revealed that after competitive matches, overnight HRV indices (ie, increased low frequency [LF, in ms^2] and reduced high frequency [HF, in ms^2]) were significantly altered compared with the rest day. Though, most studies involving overnight HRV analysis did not detail the standardization of the data acquisition and interpretation. This is a crucial step to allow for comparison of results obtained in different studies.

In this regard, we searched the literature for studies describing the methods of overnight HRV analysis with enough details to allow for the replication of the procedures. Accordingly, the "slow-wave sleep episode" (SWSE)[12,15,16] was one of the chosen methods to assess HRV. The SWSE considers (1) the first 10 minutes of the first low and regular HR episode lasting at least 15 minutes; (2) the lowest SD of RR intervals (SD of normal to normal RR intervals [SDNN]) throughout the period of interest; (3) a round Poincaré plot (ie, a round cluster of points in RR intervals plotted as a function of the previous one); and (4) a low interbeat autocorrelation between successive RR intervals (ie, correlation coefficient of the Poincaré plot <.5). Using this method, it was observed that a single session of supramaximal intermittent exercise caused a reduction in the vagally mediated HRV indices among young nonathletes during the night sleep following the exercise.[12] It is important to highlight that this method requires the analysis of "only" 10 minutes out of many hours of sleep.

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In contrast, Myllymaki et al[17] proposed to analyze the overnight sleep cardiac autonomic activity using an "hour-by-hour" approach, thus using all the RR intervals recorded throughout the hours of sleep. They found that vigorous late-night exercise did not disturb sleep quality.[17] However, it affected the cardiac autonomic control during the first sleeping hours. To date, no studies have concurrently analyzed the sensitivity of both methods (SWSE or "hour-by-hour") in detecting the effects of acute training sessions in highly trained athletes, with special reference to assessing the autonomic activity following late-night team sports training.

Therefore, the purpose of this study was to assess the sensitivity of nocturnal HRV methods to the effects of late-night soccer training sessions in female athletes. We also aimed to compare training days with nontraining days with regards to overnight cardiac autonomic activity.

Methods

Subjects

In total, 11 female soccer players (5 defenders, 4 midfielders, and 2 forwards; age = 21.5 [0.9] y, height = 162.6 [1.9] cm, and body mass = 56.7 [1.7] kg) competing in the first division of the Portuguese soccer league participated in the study. Prior to the study commencement, the study design was carefully explained to the subjects, and a written informed consent was obtained. The study followed the Declaration of Helsinki and was approved by the University of Porto, Faculty of Sports, ethics committee (CEFADE 03.2017).

Design

This was a single-group observational study that measured internal training load (TL) (by mean of training impulse [TRIMP] and session rating of perceived exertion [sRPE]), nocturnal cardiac autonomic activity, and well-being ratings during a 1-week competitive in-season cycle in female soccer players.

The training sessions planned by the coach for the observation week are outlined in Table 1. All training sessions (Monday, Wednesday, and Friday) started at the same hour of day (21:00 h). Three training sessions were completed (n = 3). Rest days were considered as all the other nights without previous training session (n = 3).

During the study period, the subjects were asked to follow their normal sleep-wake cycle in their own houses to avoid disturbing their habits.[17] Each athlete self-performed the wearable RR interval recordings at home, being instructed to attach the device (Firstbeat Bodyguard 2®; Firstbeat Technologies, Jyväskylä, Finland) to the right side of the body, below the collar bone, with the other end attached to the left side on the rib cage (using ECG electrodes; Ambu® BlueSensor L, Copenhagen, Denmark), just before going to the bed. The device used in this study is considered valid when compared with standard electrocardiogram equipment to detect heartbeats.[18] In the following morning, they were instructed to gently remove the electrodes and the device before leaving the bed. It is important to highlight that there was some variation on the time the players went to bed (ie, between 00:00 h and 01:00 h, approximately), after night-training session days and rest days, because their habits were not constrained by the study procedures, granting high ecological validity to the study.

During each night-training session, HR and TRIMP[19] (calculated using the following formula: $T \times [(HR_{ex} - HR_{rest})/(HR_{max} - HR_{rest})] \times 0.86e^{1.67[(HR_{ex}-HR_{rest})/(HR_{max}-HR_{rest})]}$; where T = duration of the workout, HR_{ex} = heart rate during workout, HR_{rest} = resting heart rate, HR_{max} = maximal heart rate, and $e \sim 2.718$) were recorded. Approximately 15 minutes before each training session,[20] players were asked to rate their well-being scores relative to fatigue, stress level, delayed onset muscle soreness, and sleep quality/disorders on a scale with a range of 1 to 7 in accordance with Hooper et al.[21] RPE was collected after each night-training session.[22]

During the 5 weeks prior to the study, players were familiarized with the devices used during the investigation to avoid training activities or the sleep pattern be disturbed using an extraneous equipment. All night-training sessions were performed on outdoor artificial grass pitch, which was the usual training venue of the investigated team, where ambient temperature normally ranged between 18°C and 20°C.

Methodology

Training Load. Heart rate data during the training sessions were recorded via radio telemetry Firstbeat Sports (Firstbeat Sports, Jyväskylä, Finland) and was exported to the Firstbeat Sports Server® software (version 4.7.3.1). A TL score (ie, Firstbeat TRIMP) was calculated automatically by the Firstbeat Sports software.

In addition, the sRPE was determined using the CR-10 rating-of-perceived-exertion (RPE) scale modified by Foster et al[23] that translates the player's perception of effort into a numerical score between 0 and 10 (training intensity as indicated by RPE). RPE was obtained approximately 15 to 30 minutes after the training session, as described by Foster.[24]

Subjective Well-Being Ratings. The Hooper index is a method based on self-analysis questionnaire involving the well-being ratings relative to fatigue, stress level, delayed onset muscle soreness, and sleep quality/disorders.[21]

Cardiac Autonomic Activity. Two different methods were used to analyze the cardiac autonomic activity during night sleep: the SWSE method (as proposed by Brandenberger et al[16]) and the "hour-by-hour" method (as proposed by Myllymaki et al[17]).

The SWSE method records the 10 minutes of normal RR interval period using Kubios HRV 3.0.0® software (Kubios Oy, Kuopio, Finland) considering the criteria outlined in the introduction. The hour-by-hour method divides the overnight sleep into consecutive 1-hour periods for the cardiac autonomic activity

Table 1 Typical Weekly Training Program for the Female Soccer Players

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Training week	Conditioning 10′ SSG 80′	Rest	Conditioning 10′ ST/PT 20′ TEC/TAC 60′	Rest	Conditioning 10′ TEC/TAC 80′	Rest

Abbreviations: SSG, small-sided games of different formats (small = 4 × 4 and large = 10 × 10); ST/PT, strength–power training; TAC, tactical training; TEC, technical training. Note: Conditioning aimed at improving aerobic capacity involving interval and continuous runs.

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Table 3 Variations of Subjective Ratings, HR_{ex}, and TRIMP During the Night-Training Session Days (N = 11)

	TD1, mean (SD); min–max	TD2, mean (SD); min–max	TD3, mean (SD); min–max
sRPE, a.u.	281.8 (117.9); 90.0–490.0	369.0 (111.7); 231.0–539.0	324.7 (115.3); 234.0–616.0
HR_{ex}, bpm	138.2 (13.2); 120.0–159.0	149.5 (16.8); 127.0–176.0	139.0 (14.0); 114.0–161.0
TRIMP, a.u.	77.5 (36.5); 18.0–132.0	102.3 (37.0); 59.0–173.0	110.8 (31.6); 52.0–156.0
Rating of sleep, a.u.	2.4 (0.9); 1.0–4.0	3.0 (0.8); 2.0–4.0	3.5 (1.2); 1.0–5.0
Rating of stress, a.u.	2.1 (1.2); 1.0–4.0	2.5 (1.0); 1.0–4.0	2.7 (1.1); 1.0–4.0
Rating of fatigue, a.u.	3.6 (1.7); 1.0–6.0	3.5 (1.5); 1.0–6.0	3.5 (1.4); 2.0–6.0
Rating of muscle soreness, a.u.	3.5 (1.6); 1.0–6.0	3.3 (1.2); 2.0–5.0	3.1 (1.2); 2.0–5.0
Hooper index, a.u.	11.6 (4.4); 5.0–17.0	12.3 (3.3); 7.0–16.0	12.8 (3.2); 7.0–17.0

Abbreviations: a.u., arbitrary units; bpm, beats per minute; HR_{ex}, the average heart rate during exercise; max, maximum; min, minimum; sRPE, session rating of perceived exertion; TD, training day; TRIMP, training impulse. Note: All data are presented as mean (SD).

Table 4 Means, SDs, and *ES*s Using Partial Eta-Squared Calculations and 95% CI of Cardiac Autonomic Activity (SWSE Method) Over the 6 Nights After Late-Night Training Sessions and Rest Days (N = 11)

Cardiac autonomic activity (SWSE method)	First night (TD1)	Second night (RD1)	Third night (TD1)	Forth night (RD2)	Fifth night (TD1)	Sixth night (RD3)	*P* (ANOVA)	η_p^2 (95% CI)
Heart rate, bpm	57.0 (5.3)	55.6 (5.4)	57.3 (5.0)	55.9 (5.6)	57.9 (5.4)	56.8 (5.5)	.35	.103 (.01–.20)
lnRR interval, ms	6.97 (0.09)	7.0 (0.09)	6.96 (0.09)	7.00 (0.10)	6.95 (0.09)	6.97 (0.10)	.32	.107 (.01–.21)
lnRMSSD, ms	4.09 (0.35)	4.03 (0.51)	4.02 (0.49)	4.20 (0.60)	3.92 (0.57)	3.94 (0.67)	.15	.163 (.01–.26)
lnSDNN, ms	3.79 (0.31)	3.74 (0.52)	3.73 (0.48)	3.86 (0.59)	3.62 (0.56)	3.62 (0.59)	.18	.138 (.01–.25)
$lnSD_1$, ms	3.74 (0.35)	3.69 (0.51)	3.68 (0.48)	3.86 (0.60)	3.58 (0.58)	3.60 (0.68)	.15	.146 (.01–.26)
$lnSD_2$,ms	3.79 (0.33)	3.76 (0.55)	3.74 (0.49)	3.83 (0.61)	3.64 (0.61)	3.61 (0.53)	.26	.119 (.01–.22)
lnLF, ms^2	6.01 (0.88)	6.00 (1.48)	5. 88 (1.31)	6.17 (1.24)	5.62 (1.24)	5.62 (1.25)	.30	.115 (.01–.22)
lnHF, ms^2	7.16 (0.61)	6.99 (0.95)	7.01 (0.88)	7.24 (1.08)	6.81 (1.07)	6.80 (1.16)	.18	.137 (.01–.25)
LF/HF, ms^2	0.37 (0.18)	0.50 (0.48)	0.46 (0.43)	0.41 (0.29)	0.40 (0.33)	0.36 (0.21)	.68	.059 (.00–.14)
lnTP, ms	7.50 (0.65)	7.41 (1.10)	7.39 (0.94)	7.60 (1.16)	7.15 (1.10)	7.14 (1.12)	.16	.143 (.01–.25)

Abbreviations: ANOVA, analysis of variance; bpm, beats per minute; CI, confidence interval; *ES*, effect size; HF, high frequency; LF, low frequency; LF/HF, ratio of the low-to-high frequency power; RD, rest day; RMSSD, the square root of the mean of the sum of the squares of differences between adjacent normal-to-normal intervals; RR interval, variations between consecutive heartbeats (beat to beat); SD_1, short-term beat-to-beat variability; SD_2, long-term beat-to-beat variability; SDNN, SD of normal-to-normal RR intervals; SWSE, slow-wave sleep episode; TD, training day; TP, entire power spectral area. Note: All data are presented as mean (SD).

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0.26–0.76, small) and the 6 h (*ES* = 0.42; 95% CI, 0.22–0.62, small) compared with the 2 h. Also, parasympathetic-related $lnSD_1$ was significantly increased ($P < .001$) in the 5 h (*ES* = 0.30; 95% CI, 0.15–0.45, small) compared with 2 h. In the rest days, lnLF was significantly increased ($P < .001$) in the 6 h compared with the 1 h (*ES* = 0.44; 95% CI, 0.23–0.65, small) and the 3 h (*ES* = 0.22; 95% CI, 0.11–0.33, small). Moreover, lnTP was significantly increased ($P < .001$) in the 6 h (*ES* = 0.34; 95% CI, 0.17–0.51, small) compared with the 3 h. No differences between night-training session days and rest days were found in relation to sympathovagal balance LF/HF ($P > .05$).

The CV% and ICC (95% CI) of lnRMSSD are presented in Table 6. In all cases, the CV% was low (4.21%–6.14%), and the ICC was very large to near perfect (.89–.95), attesting the high reproducibility of the indices across the days, irrespective of training or not in that day.

Discussion

The present study evaluated the sensitivity of nocturnal HRV methods to the effects of late-night soccer training sessions in female athletes. No significant HRV changes were noticed during the training days compared with the nontraining days. These findings may indicate that the referred methods are not sensitive enough to detect the overnight cardiac autonomic activity disturbances. Alternatively, and more likely, it could also be stated that the amount of TL prescribed to the investigated soccer team was not high enough to cause meaningful changes on the cardiac sympathetic and parasympathetic activities. Nevertheless, some specific temporal changes were detected in the "hour-by-hour" vagally mediated HRV (ie, lnRMSSD and lnHF), suggesting an increment in the cardiac parasympathetic modulation in the hours preceding awakening in the training days.

Regarding the TL, it appears that the sRPE (281.8 [117.9] to 369.0 [111.7] arbitrary units [a.u.]) and TRIMP (77.5 [36.5] to 110.8 [31.6] a.u.) during 3 night-training sessions were not high enough to cause overnight changes in the sympathetic and parasympathetic systems. In a study conducted by Impellizzeri et al[22] involving 19 young male soccer players, the mean sRPE during soccer-specific sessions ranged between 343 (65) and 634 (116). Moreover, Milanez et al[31] reported that professional female futsal players accumulated between 343 and 419 a.u. (sRPE).

Table 5 Means, SDs, Statistically Significant Differences, and *ES*s Using Partial Eta-Squared Calculations and 95% CI of Different Cardiac Autonomic Activity (Hour-by-Hour Method) During Night Sleep After 3 Night-Training Session Days and 3 Rest Days (N = 11)

Cardiac autonomic activity	Different conditions	1 h	2 h	3 h	4 h	5 h	6 h	*P* (ANOVA)	η_p^2 (95% CI)
Heart rate, bpm	TD	64.5 (6.1)	62.7 (5.5)	61.4 (5.6)	59.6 (4.8)	58.2 (4.6)[a]	58.9 (4.8)	.001*	.610 (.45–.66)
	RD	58.8 (5.0)[b]	57.6 (5.5)[b]	57.6 (4.7)[b]	56.5 (4.7)	56.4 (5.2)	56.4 (4.79)		
lnRR interval, ms	TD	6.86 (0.09)	6.88 (0.09)	6.90 (0.09)	6.93 (0.08)[a]	6.95 (0.08)[a]	6.93 (0.11)	.001*	.587 (.42–.64)
	RD	6.95 (0.09)[b]	6.96 (0.09)[b]	6.97 (0.08)[b]	6.98 (0.08)	6.99 (0.09)	6.99 (0.08)		
lnRMSSD, ms	TD	4.15 (0.35)	4.05 (0.35)	4.09 (0.31)	4.18 (0.32)	4.31 (0.34)[c]	4.33 (0.32)[c]	.001*	.455 (.26–.52)
	RD	4.26 (0.36)	4.22 (0.45)	4.24 (0.35)	4.31 (0.36)	4.39 (0.38)	4.42 (0.34)		
lnSDNN, ms	TD	4.04 (0.25)	3.95 (0.31)	3.98 (0.27)	4.04 (0.30)	4.12 (0.33)	4.14 (0.30)	.001*	.381 (.18–.45)
	RD	4.08 (0.28)	4.03 (0.37)	4.07 (0.29)	4.12 (0.32)	4.21 (0.33)	4.24 (0.31)		
$lnSD_1$, ms	TD	3.80 (0.35)	3.70 (0.34)	3.74 (0.31)	3.83 (0.33)	3.96 (0.34)[c]	3.98 (0.32)	.001*	.454 (.26–.52)
	RD	3.92 (0.36)	3.88 (0.45)	3.89 (0.35)	3.96 (0.36)	4.05 (0.38)	4.07 (0.34)		
$lnSD_2$, ms	TD	4.18 (0.21)	4.09 (0.31)	4.13 (0.27)	4.17 (0.30)	4.23 (0.33)	4.25 (0.31)	.001*	.321 (.12–.39)
	RD	4.19 (0.25)	4.14 (0.33)	4.18 (0.29)	4.23 (0.32)	4.31 (0.31)	4.36 (0.31)		
lnLF, ms^2	TD	7.02 (0.48)	6.94 (0.74)	7.03 (0.64)	7.07 (0.71)	7.15 (0.80)	7.25 (0.68)	.001*	.287 (.09–.35)
	RD	7.12 (0.54)	6.98 (0.80)	7.10 (0.64)	7.17 (0.77)	7.41 (0.68)	7.49 (0.68)[d,e]		
lnHF, ms^2	TD	7.17 (0.73)	7.04 (0.64)	7.03 (0.61)	7.23 (0.62)	7.51 (0.66)[c]	7.52 (0.65)	.001*	.429 (.23–.49)
	RD	7.30 (0.67)	7.30 (0.79)	7.33 (0.63)	7.46 (0.66)	7.64 (0.71)	7.67 (0.65)		
LF/HF, ms^2	TD	1.03 (0.61)	1.02 (0.44)	1.27 (0.77)	0.99 (0.62)	0.85 (0.43)	0.85 (0.34)	.09	.183 (.01–.24)
	RD	0.86 (0.43)	0.85 (0.46)	0.91 (0.42)	0.86 (0.41)	0.90 (0.43)	0.96 (0.50)		
lnTP, ms	TD	7.91 (0.56)	7.80 (0.65)	7.88 (0.54)	7.97 (0.60)	8.15 (0.68)	8.19 (0.63)	.001*	.384 (.18–.45)
	RD	7.97 (0.56)	7.96 (0.74)	8.04 (0.58)	8.13 (0.66)	8.33 (0.65)	8.39 (0.62)[e]		

Abbreviations: ANOVA, analysis of variance; bpm, beats per minute; CI, confidence interval; *ES*, effect size; HF, high frequency; LF, low frequency; LF/HF, ratio of the low-to-high frequency power; RD, rest day; RMSSD, the square root of the mean of the sum of the squares of differences between adjacent normal to normal intervals; RR interval, variations between consecutive heartbeats (beat to beat); SD_1, short-term beat-to-beat variability; SD_2, long-term beat-to-beat variability; SDNN, SD of normal to normal RR intervals; TD, training day; TP, entire power spectral area. Note: All data are presented as mean (SD). All variables were calculated for the whole-night sleep period. [a]Significant difference versus 1 h of TD night. [b]Significant difference interconditions. [c]Significant difference versus 2 h of TD night. [d]Significant difference versus 1 h of RD night. [e]Significant difference versus 3 h of RD night.

*Statistical significance is expressed as $P < .05$.

Table 6 CVs, ICCs, and 95% CIs Representing Nocturnal Changes, Using 2 Different Methods, in the lnRMSSD (N = 11)

	Hour-by-hour method						
HRV index	1 h	2 h	3 h	4 h	5 h	6 h	SWSE method (TD1, RD1; TD2, RD2; and TD3, RD3)
lnRMSSD							
CV%	5.32	5.61	5.54	5.29	4.21	4.87	6.14
ICC	.92	.93	.90	.89	.95	.90	.95
(95% CI)	(.81–.98)	(.85–.98)	(.77–.97)	(.75–.97)	(.89–.99)	(.78–.97)	(.89–.99)

Abbreviations: CI, confidence interval; CV, coefficient of variation; HRV, heart-rate variability; ICC, intraclass correlation coefficient; lnRMSSD, natural logarithm of the square root of the mean of the sum of the squares of differences between adjacent normal RR intervals; RD, rest day; RR interval, variations between consecutive heartbeats (beat to beat); SWSE, slow-wave sleep episode; TD, training day.

Furthermore, in that study, it was possible to see (in a subsample) increased stress symptoms (ie, reduced salivary immunoglobulin A and number of "worse than normal" responses to the Daily Analysis of Life Demands for Athletes questionnaire)[11] when the sRPE overcame ~500 a.u. per day. Therefore, it can be hypothesized that high levels of TL (eg, >600 a.u. sRPE), which is typical during soccer matches,[22] can substantially disturb overnight HRV. This topic deserves future studies. For the moment, it is clear that in highly trained female soccer players, TL in the range observed herein does not induce significant changes in HRV during postexercise night sleep. Supporting this notion, the perceived well-being (as established by Hooper et al[21]) of the players across the training days did not significantly change, thus indicating that the amount of TL of the investigated week was well tolerated by the players.

It is currently accepted that overnight sleep measurements over a number of days are appropriate for tracking the recovery of HRV following high-intensity exercise.[12] Notably, the SWSE is considered as the most restorative sleep stage[32] due to the pronounced vagal tone compared with other sleep episodes or wake activities.[14] In a previous study,[12] by using this method, it was shown that high-intensity interval training performed in the morning by team sport

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players was capable of disturbing the SWSE HRV indices 12 hours later (overnight period). Hence, it was expected that late-night soccer training would also disturb the cardiac autonomic activity in the present study. However, the training days did not result in significantly different HRV values compared with the rest days. Hence, the findings suggest that soccer training (mostly technical and tactical drills) is not as stressful as "generic" physical training involving interval runs, especially due to the relatively low TL undertaken by the players, as previously mentioned.

However, in this study, a late-night exercise caused significantly ($P < .001$) higher HR during sleep during the first 3 sleeping hours ($\eta_p^2 = .610$; 95% CI, .45–.66, large effect), using the "hour-by-hour" analysis. Previous studies concerning this topic have reported elevated HR during sleep after a strenuous exercise day[33] and prolonged submaximal exercise.[34] In fact, high-intensity running exercise has shown to reduce HRV for 30 to 60 minutes after exercise in trained and highly trained subjects,[35] whereas HR remained elevated for a longer period (up to 2 h).[35] Interestingly, some specific time-dependent changes were detected ($P < .001$) in the "hour-by-hour" overnight HRV during the training days, suggesting an increased cardiac autonomic modulation (as expressed by both lnLF [$\eta_p^2 = .287$; 95% CI, .09–.35, large effect] and lnHF [$\eta_p^2 = .429$; 95% CI, .23–.49, large effect]) in the hours preceding awakening. Thus, it appears that the "hour-by-hour" HRV method was more sensitive to detect overnight changes in sympathetic and parasympathetic systems compared with the SWSE method.

The lnRMSSDcv has also been assessed in studies involving highly trained athletes as a marker of weekly variation in daily assessed lnRMSSD.[36] Esco et al[36] found in a collegiate male runner throughout a competitive season that 8-km endurance race time was related to lnRMSSDcv ($r = .92$), indicating that a high variation in the weekly cardiac vagal activity is associated with poor performance. In addition, high lnRMSSDcv was associated positively with perceived fatigue and negatively with physical fitness of female soccer players.[8] In contrast, a reduced lnRMSSDcv without a clear decrease in the lnRMSSD appears to reflect improved training adaptation[36] and possibly a higher level of readiness to perform.[36] In our study, lnRMSSD derived from both methods (SWSE and "hour-by-hour") displayed low CVs (4.21%–6.14%). The high ICC (.89–.95) found in all measures strengthen the consistency of the HRV measured in the current study and support previous a finding about the high levels of reliability of HRV indices in athletes.[6,28] Interspersing measurements by long intervals (eg, 7 d) are shown to reduce the reliability of lnRMSSD so that CV can increase to >12%.[28] However, for the purposes of monitoring athletes, measurements performed during consecutive days or within the same week are more useful to interpret adaptations.[6–8,13]

Of importance, this study comprised only 1 week of observation. However, as it was a typical training week, it can be inferred that players of the investigated team were coupling well with the loads, given that their lnRMSSDcv did not indicate any sign of perturbation of cardiac autonomic activity.[8] A recent study showed that lnRMSSDcv measured in swimmers can increase to values >10% during overload periods.[37] However, caution should be taken while comparing studies because in our case, the HRV was measured during sleep, whereas in most investigations, it was measured early in the morning[8] or at training facilities arrival.[4,6,7]

Conclusion and Practical Applications

This study showed that changes on HR during sleep after late-night soccer training sessions can occur, especially during the first sleeping hours. However, late-night soccer training does not seem to affect SWSE and "hour-by-hour" HRV indices in comparison with rest days. These findings may indicate that these methods are not sensitive enough to detect the overnight cardiac autonomic activity disturbances. Alternatively, and more likely, our findings indicate that the late-night TLs undertaken by the investigated team, as measured by TRIMP (77.5 [36.5] to 110.8 [31.6] a.u.) and sRPE (281.8 [117.9] to 369.0 [111.7] a.u.), were not high enough to disturb the cardiac autonomic function of highly trained female soccer players during their sleep hours. In conclusion, late-night soccer training does not seem to affect SWSE and "hour-by-hour" HRV indices in highly trained athletes, but it elevated HR, during the first 3 sleeping hours after the night-training sessions, suggesting that the latter method can be more useful to detect acute training–related changes. However, as the implementation of both methods resulted in highly reliable lnRMSSD measures, it can be put forth that overnight HRV can be sensitive (ie, high-internal responsiveness) to positive and negative changes due to training and competition.

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References

1. Task Force. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Circulation*. 1996;93:1043–1065. PubMed doi:10.1161/01.CIR.93.5.1043
2. Plews DJ, Laursen PB, Stanley J, Kilding AE, Buchheit M. Training adaptation and heart rate variability in elite endurance athletes: opening the door to effective monitoring. *Sports Med*. 2013;43(9):773–781. PubMed doi:10.1007/s40279-013-0071-8
3. Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med*. 2014;44(suppl 2):139–147. doi:10.1007/s40279-014-0253-z
4. de Freitas VH, Pereira LA, de Souza EA, Leicht AS, Bertollo M, Nakamura FY. Sensitivity of the Yo-Yo Intermittent Recovery Test and cardiac autonomic responses to training in futsal players. *Int J Sports Physiol Perform*. 2015;10(5):553–558. PubMed doi:10.1123/ijspp.2014-0365
5. Esco MR, Flatt AA, Nakamura FY. Initial weekly HRV response is related to the prospective change in VO_{2max} in female soccer players. *Int J Sports Med*. 2016;37(6):436–441. PubMed doi:10.1055/s-0035-1569342
6. Nakamura FY, Pereira LA, Rabelo FN, et al. Monitoring weekly heart rate variability in futsal players during the preseason: the importance of maintaining high vagal activity. *J Sports Sci*. 2016;34(24):2262–2268. doi:10.1080/02640414.2016.1186282
7. Flatt AA, Esco MR, Nakamura FY. Individual heart rate variability responses to preseason training in high level female soccer players. *J Strength Cond Res*. 2016;31(2):531–538. PubMed doi:10.1519/JSC.0000000000001482

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8. Flatt AA, Esco MR, Nakamura FY, Plews DJ. Interpreting daily heart rate variability changes in collegiate female soccer players. *J Sports Med Phys Fitness*. 2017;57(6):907–915. PubMed doi:10.23736/S0022-4707.16.06322-2
9. Le Meur Y, Pichon A, Schaal K, et al. Evidence of parasympathetic hyperactivity in functionally overreached athletes. *Med Sci Sports Exerc*. 2013;45:2061–2071. doi:10.1249/MSS.0b013e3182980125
10. Bellenger CR, Karavirta L, Thomson RL, Robertson EY, Davison K, Buckley JD. Contextualizing parasympathetic hyperactivity in functionally overreached athletes with perceptions of training tolerance. *Int J Sports Physiol Perform*. 2016;11(7):685–692. PubMed doi:10.1123/ijspp.2015-0495
11. Rushall BS. A tool for measuring stress tolerance in elite athletes. *J Appl Sport Psychol*. 1990;2:51–66. doi:10.1080/10413209008406420
12. Al Haddad H, Laursen PB, Ahmaidi S, Buchheit M. Nocturnal heart rate variability following supramaximal intermittent exercise. *Int J Sports Physiol Perform*. 2009;4(4):435–447. PubMed doi:10.1123/ijspp.4.4.435
13. Boullosa DA, Abreu L, Nakamura FY, Munoz VE, Dominguez E, Leicht AS. Cardiac autonomic adaptations in elite Spanish soccer players during preseason. *Int J Sports Physiol Perform*. 2013;8(4):400–409. PubMed doi:10.1123/ijspp.8.4.400
14. Bricout VA, DeChenaud S, Favre-Juvin A. Analyses of heart rate variability in young soccer players: the effects of sport activity. *Auton Neurosci*. 2010;154(1):112–116. doi:10.1016/j.autneu.2009.12.001
15. Buchheit M, Simon C, Piquard F, Ehrhart J, Brandenberger G. Effect of increased training load on vagal-related indexes of heart rate variability: a novel sleep approach. *Am J Physiol Heart Circ Physiol*. 2004;287:H2813–H2818. PubMed doi:10.1152/ajpheart.00490.2004
16. Brandenberger G, Buchheit M, Ehrhart J, Simon C, Piquard F. Is slow wave sleep an appropriate recording condition for heart rate variability analysis? *Auton Neurosci Basic Clin*. 2005;121:81–86. doi:10.1016/j.autneu.2005.06.002
17. Myllymaki T, Kyrolainen H, Savolainen K, et al. Effects of vigorous late-night exercise on sleep quality and cardiac autonomic activity. *J. Sleep Res*. 2011;20:146–153. PubMed doi:10.1111/j.1365-2869.2010.00874.x
18. Parak J, Korhonen I. Accuracy of Firstbeat BodyGuard 2 beat-to-beat heart rate monitor. 2015. https://www.firstbeat.com/app/uploads/2015/10/white_paper_bodyguard2_final.pdf. Accessed May 8, 2017.
19. Banister EW. Modeling elite athletic performance. In: MacDougall JD, Wenger HA, Green HJ, eds. *Physiological Testing of the High-Performance Athlete*. Champaign, IL: Human Kinetics; 1991:403–424.
20. Haddad M, Chaouachi A, Wong DP, et al. Influence of fatigue, stress, muscle soreness and sleep on perceived exertion during submaximal effort. *Physiol Behav*. 2013;119:185–189. PubMed doi:10.1016/j.physbeh.2013.06.016
21. Hooper SL, Mackinnon LT, Howard A, Gordon RD, Bachmann AW. Markers for monitoring overtraining and recovery. *Med Sci Sports Exerc*. 1995;27(1):106–112. doi:10.1249/00005768-199501000-00019
22. Impellizzeri FM, Rampinini E, Coutts AJ, Sassi A, Marcora SM. Use of RPE-based training load in soccer. *Med Sci Sports Exerc*. 2004;36(6):1042–1047. PubMed doi:10.1249/01.MSS.0000128199.23901.2F
23. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res*. 2001;15(1):109–115. PubMed
24. Foster C. Monitoring training in athletes with reference to overtraining syndrome. *Med Sci Sports Exerc*. 1998;30(7):1164–1168. PubMed doi:10.1097/00005768-199807000-00023
25. Tarvainen MP, Niskanen JP, Lipponen JA, Ranta-Aho PO, Karjalainen PA. Kubios HRV—heart rate variability analysis software. *Comput Methods Programs Biomed*. 2014;113(1):210–220. PubMed doi:10.1016/j.cmpb.2013.07.024
26. Mourot L, Bouhaddi M, Perrey S, et al. Decrease in heart rate variability with overtraining: assessment by the Poincaré plot analysis. *Clin Physiol Funct Imaging*. 2004;24(1):10–18. PubMed doi:10.1046/j.1475-0961.2003.00523.x
27. Song HS, Lehrer PM. The effects of specific respiratory rates on heart rate and heart rate variability. *Appl Psychophysiol Biofeedback*. 2003;28(1):13–23. PubMed doi:10.1023/A:1022312815649
28. Al Haddad H, Laursen PB, Chollet D, Ahmaidi S, Buchheit M. Reliability of resting and postexercise heart rate measures. *Int J Sports Med*. 2011;32(8):598–605. PubMed doi:10.1055/s-0031-1275356
29. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.
30. Hopkins WG. Statistics in observational studies. In: Verhagen E, van Mechelen W, eds. *Methodology in Sports Injury Research*. Oxford, UK: OUP; 2009:69–81.
31. Milanez VF, Ramos SP, Okuno NM, Boullosa DA, Nakamura FY. Evidence of a non-linear dose–response relationship between training load and stress markers in Elite Female Futsal Players. *J Sports Sci Med*. 2014;13(1):22–29. PubMed
32. Akerstedt T, Hume K, Minors D, Waterhouse J. Good sleep—its timing and physiological sleep characteristics. *J Sleep Res*. 1997;6:221–229. PubMed doi:10.1111/j.1365-2869.1997.00221.x
33. Hauri P. Effects of evening activity on early night sleep. *Psychophysiology*. 1968;4:267–277. doi:10.1111/j.1469-8986.1968.tb02767.x
34. Mischler I, Vermorel M, Montaurier C, et al. Prolonged daytime exercise repeated over 4 days increases sleeping heart rate and metabolic rate. *Can J Appl Physiol*. 2003;28:616–629. PubMed doi:10.1139/h03-047
35. Seiler S, Haugen O, Kuffel E. Autonomic recovery after exercise in trained athletes: intensity and duration effects. *Med Sci Sports Exerc*. 2007;39:1366–1373. PubMed doi:10.1249/mss.0b013e318060f17d
36. Esco MR, Snarr RL, Flatt A, Leatherwood M, Whittaker A. Tracking changes in maximal oxygen consumption with the heart rate index in female collegiate soccer players. *J Hum Kinet*. 2014;42:103–111. PubMed doi:10.2478/hukin-2014-0065
37. Flatt AA, Hornikel B, Esco MR. Heart rate variability and psychometric responses to overload and tapering in collegiate sprint-swimmers. *J Sci Med Sport*. 2017;20(6):606–610. PubMed doi:10.1016/j.jsams.2016.10.017

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Study 2

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ORIGINAL INVESTIGATION

Does Night Training Load Affect Sleep Patterns and Nocturnal Cardiac Autonomic Activity in High-Level Female Soccer Players?

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Purpose: To analyze whether exercise training conducted at night disturbs sleep and affects nocturnal cardiac autonomic control in high-level female athletes. ***Methods:*** A total of 18 high-level female soccer players (mean [SD] age 20.4 [2.1] y) wore actigraphs and heart-rate (HR) monitors during night sleep throughout night training days (n = 8) and resting days (n = 8), for 3 consecutive weeks. This was a longitudinal study that measured internal training load, sleep, nocturnal cardiac autonomic activity, and well-being ratings prior to training sessions. ***Results:*** Training load varied across training days (eg, training impulse range, mean [SD]; effect size, ES [95% confidence interval]: 72.9 [18.8] to 138.4 [29.6] a.u.; $F_{4,62} = 32.331$; $\eta_p^2 = .673$ [.001–.16], large effect; $P < .001$). However, no differences in subjective well-being ratings were observed, although ES was large. Total sleep time (training days vs resting days: 07:17 [00:47] h vs 07:51 [00:42] h; ES = 0.742 [0.59–0.92], $P = .005$; moderate effect) and sleep-onset time (00:58 [00:19] h vs 00:44 [00:16] h; ES = 0.802 [0.68–0.94], $P = .001$; moderate effect) were negatively affected after night training. In addition, small effects were detected for wake-up time, time in bed, and sleep latency ($P > .05$). No differences were detected in HR variability during sleep (range of lnRMSSD: 4.3 [0.4] to 4.5 [0.4] ln[ms] vs 4.6 [0.3] to 4.5 [0.4] ln[ms]; $F_{3,52} = 2.148$; $P > .05$; $\eta_p^2 = .112$ [.01–.25], medium effect), but HR during sleep was significantly higher after training days (range of HR: 56 [4] to 63 [7] beats/min vs 54 [4] to 57 [6] beats/min; $F_{2,32} = 15.956$; $P < .001$; $\eta_p^2 = .484$ [.20–.63], large effect). ***Conclusion:*** Overall, the results indicate that exercise training conducted at night may disturb sleep and affect HR, whereas limited effects can be expected in HR variability assessed during sleep in high-level female soccer players.

Keywords: accelerometer, autonomic nervous system, football, heart-rate variability, recovery

Sleep is considered the most important and accessible daily recovery strategy. However, despite its importance to psychological and physiological recovery, athletes often sleep less than recommended.[1] Although a minimum of 7 hours of sleep per night is generally recommended to promote optimal health and cognitive function among adults aged 18 to 60 years,[2] athletes usually sleep for less than 7 hours.[3] In addition, due to their habitual mental and physical exertion demands (eg, double daily training sessions), athletes require more accumulated sleep time. In fact, extended sleep time can lead to better psychomotor performance and technical accuracy,[4] with likely effects on competitive performance.[5]

Several athletes train or compete during the late evening. For instance, high-level female soccer players habitually train at very late hours (21:00 h), close to bedtime sleep, due to their daily life commitments (eg, job, university) that need to be reconciled with training schedules.[6]

It is currently accepted that overnight sleep measurements over consecutive days are appropriate for tracking the recovery of heart rate (HR) variability (HRV) following high-intensity exercise.[7] In fact, monitoring training-related cardiac autonomic responses has been facilitated by the use of ultra-short-term HRV measurement after waking.[8] In spite of its usefulness, this method does not allow analysis of the time course of cardiac autonomic recovery postexercise or quantification of HRV during periods of longer steady physiological state.[7] In this sense, HRV recordings taken during night sleep could be an interesting alternative.[6]

Bricout et al[9] revealed that after competitive matches, overnight HRV indices (ie, increased low frequency [LF, in milliseconds squared] and reduced high frequency [HF, in milliseconds squared]) were significantly altered compared with rest days. Interestingly, in a recent study[6] it was shown that late-night soccer training did not affect HRV indices, using the "hour-by-hour" method (recording all RR intervals over the night sleep) as proposed by Myllymaki et al,[10] in comparison with rest days. However, HR was increased during the first 3 sleeping hours compared with the control situation. It was speculated that the training loads experienced by the team were not high enough to substantially disturb the cardiac autonomic function during sleep hours. Nonetheless, this study comprised only 1 week of observation, and the results need to be confirmed in longer and more representative observations. Furthermore, sleep patterns were not quantified using objective methods, such as accelerometry.

During congested competitive periods, soccer players follow strict match and training schedules that can reduce sleep duration[1] and impair recovery processes,[11] especially when training sessions and/or competitions occur close to bedtime sleep.[11] Consequently, quantifying the sleep of athletes over several weeks in their usual environment is essential to accurately characterize normal sleep patterns. Sargent et al[12] followed elite swimmers across 14 consecutive nights and found that early morning (06:00 h) training sessions restricted sleep duration during the previous night (compared with a rest day). However, Robey et al[13] showed that total sleep time (TST) was not affected after performing early evening high-intensity training sessions (starting at ~16:30 h and finishing

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at 18:30 h) in elite youth soccer players, compared with nights where no evening training was performed. Therefore, further research is needed to determine whether regular training scheduled in the late evening (eg, after 21 h) affects sleep patterns in team-sport athletes. This knowledge could provide information on training programming in order to optimize recovery by means of implementing sleep hygiene strategies to extend sleep or planning daytime naps.[14] Furthermore, it is important to use valid load metrics to properly contextualize the effects of training late in the night on sleep patterns and the physiology. Training load can be quantified by session rating of perceived exertion (sRPE), training impulse (TRIMP), and average HR during the exercise session (HR_{ex}).[15] Moreover, Casamichana et al[16] provided evidence of the validity of these measures of internal load by showing strong relationships between sRPE, individual HR response (Edwards method), and Player Load as an objective measure provided by a global positioning system, in soccer players. Of note, in the aforementioned study in which overnight HRV was not affected by the night training sessions in female soccer players, TRIMP ranged between 77.5 and 110.8 a.u.,[6] which can be considered a low training load compared with match load.[17]

To date, no studies have simultaneously evaluated sleep patterns and HRV after late-night training sessions in female soccer players using internal training loads quantified by valid means. Interestingly, a recent study demonstrated that changes in HRV may be associated with sleep quality.[18] For example, Werner et al[19] found that higher objective and subjective sleep quality were associated with higher postwaking vagally-mediated HRV among a sample of healthy college students. Nonetheless, it is also important to highlight that sleep patterns and HRV changes that may occur during sleep after physical exercise can be influenced whether the athletes are exposed to a chronic (habitual) or acute (single) late training[20] or night official competition.[21] For example, Vitale et al[21] showed that the sleep quantity and quality of female and male athletes were acutely lower during the night immediately after the night match compared with previous or subsequent nights. In addition, Myllymaki et al[22] showed that acute physical exercise (running exercises) in physically active male subjects caused delayed recovery of nocturnal cardiac autonomic modulation, but no changes in sleep quality. However, and as already mentioned above, these results are in contrast with a recent study,[6] which showed no changes in nocturnal HRV in athletes who habitually train in the nighttime due to their daily commitments.

Therefore, the purpose of this study was to investigate whether training sessions conducted at night disturb sleep and affect cardiac autonomic control in female athletes, when compared with rest days, in a representative period of observation (3 wk). It was hypothesized that sleep patterns and/or autonomic cardiac activity would be affected by the night training sessions in high-level female athletes, when compared with rest days.

Methods

Subjects

A total of 18 high-level female semiprofessional soccer players (6 defenders, 7 midfielders, and 5 forwards; age: 21.4 [2.1] y, height: 163.3 [5.9] cm, body mass: 57.7 [5.7] kg) competing in the first division of the Portuguese Soccer League participated in the study. The study design was carefully explained to the athletes, and written informed consent was obtained. The study followed the Declaration of Helsinki and was approved by the ethics committee of the Faculty of Sports, University of Porto (CEFADE 03.2017). Inclusion criteria were aged ≥18, female, playing soccer for at least 5 years, and training at least 3 sessions per week. Exclusion criteria were tobacco use, working in a part-time night job, and medical conditions contraindicating physical exercise as diagnosed by a sports medicine physician. Two players were excluded for tobacco use and 1 player was excluded for being aged <18 years. All athletes were healthy and did not use any medication during the study. Players were requested to avoid alcohol, caffeine, and energy drink consumption during the period of the study. All athletes had similar academic and job timetables.

Design

This was a single-group longitudinal study that measured internal training load, sleep, nocturnal cardiac autonomic activity, and well-being ratings for 3 consecutive weeks (16 d of recordings; Table 1). Competitive matches were played each Sunday (matches were not

Table 1 Data Collection During 3 Consecutive Weeks (16 d of Recordings)

Week	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1 (days 2–7)	—	TL Well-being CAA Actigraphy	CAA Actigraphy	TL Well-being CAA Actigraphy	TL Well-being CAA Actigraphy	CAA Actigraphy	CAA Actigraphy
	MD	TD1	RD1	TD2	TD3	RD2	RD2
2 (days 9–14)	—	TL Well-being CAA Actigraphy	CAA Actigraphy	TL Well-being CAA Actigraphy	TL Well-being CAA Actigraphy	CAA Actigraphy	CAA Actigraphy
	MD	TD4	RD4	TD5	TD6	RD5	RD6
3 (days 16–19)	—	TL Well-being CAA Actigraphy	CAA Actigraphy	TL Well-being CAA Actigraphy	CAA Actigraphy	—	—
	MD	TD7	RD7	TD8	RD8	—	—

Abbreviations: CAA, cardiac automatic activity; MD, match day; RD, rest day; TL, training load; TD, training day. Note: TL and well-being were assessed each night training session. Cardiac autonomic activity and actigraphy were assessed during night sleep, and after each TD (represented as gray area) and RD.

included in the analysis due to organizational restraints). Eight night training days (TD; Monday, Wednesday, and Thursday) and 8 resting days (RD; Tuesday, Friday, and Saturday) were analyzed. All training sessions started at around 9 PM (21:08 [00:19] h) and lasted 01:24 (00:08) hours. The training practices proposed by the coach during each session consisted mostly of: soccer practice (skill development and small-sided games [4 vs 4]); resistance training (whole-body workouts involving power cleans and squats); and scrimmages (10 vs 10) (training volume: week 1, 4:28 [00:12] h; week 2, 4:24 [00:18] h; week 3, 4:31 [00:16] h).

The athletes were asked to follow their normal sleep–wake cycle in their own houses to avoid disturbing their regular habits. Each athlete put the RR interval monitor and wrist-worn accelerometer on at home. There was some variation in the time the athletes went to bed (bedtime, time in h:min corresponding to lying down; TD: between 00:30 and 01:10 h; RD: between 23:50 and 00:30 h; approximately). The study procedures did not constrain the sleeping habits of the athletes, granting higher ecological validity to the investigation. Each morning, the athletes were instructed to gently remove the electrodes and accelerometers before leaving bed. During each training session, sRPE, TRIMP, and HR_{ex} were assessed. Well-being was assessed prior to each training session.

One week before starting the data collection, the athletes completed a Yo-Yo Intermittent Endurance Test Level 2 (YYIET2).[23] The distance covered and peak HR (HR_{peak}) were recorded.

During the 5 weeks prior to the study, athletes were familiarized with the devices used during the investigation to avoid training activities or sleep pattern being disturbed by the equipment. All training sessions were performed on an outdoor artificial turf pitch, which was the usual training venue of the investigated team. During a 90-minute training session, the athletes were exposed to >1200 lux (horizontal luminance—using a photometer head-mounted on an optical bench and measured on a 10 m × 10-m grid within the playground; 28 compact quartz metal halide lamps with double-pinch [model: MASTER MHN-LA 2000W/956 400V] with luminous efficacy 93 lm/W and 5600 K color temperature [Tk]). Ambient temperature normally ranged between 18 and 20°C.

Methodology

Training Load. Heart-rate data during training sessions were recorded via radio telemetry (Firstbeat Sports, Jyväskylä, Finland) and exported to the Firstbeat Sports Server software (version 4.7.3.1). The software also calculated the HR_{ex}, which was expressed in absolute values (in beats per min), and as a percentage relative to the individual HR_{ex} ($\%HR_{peak}$).

Training impulse was calculated as proposed by Banister[24]:

$$\text{TRIMP} = T \times [(HR_{ex} - HR_{rest})/(HR_{peak} - HR_{rest})] \times 0.86e^{1.67([HR_{ex} - HR_{rest})/(HR_{peak} - HR_{rest})]}$$

where T represents the duration of the workout in minutes; HR_{ex}, the average HR during exercise; HR_{rest}, the average HR during rest, measured during 5 minutes of seated rest before starting each training session during the study period; HR_{peak} is determined as the highest value reached during the YYIET2 test; and e ~2.718.

The RPE was obtained approximately 15 to 30 minutes after each training session. sRPE was determined using the multiplication of the CR-10 scale by the duration of the training session.[15]

Subjective Well-Being Ratings. Approximately 15 minutes before each training session, the players completed a questionnaire involving well-being ratings relative to fatigue, stress level, delayed-onset muscle soreness, and sleep quality/disorders (scales of 1–7).[25] The Hooper Index is the summation of these 4 ratings.

Sleep Actigraphy. Sleep was assessed using 3-axial accelerometers (wGT3X-BT; ActiGraph, LLC, Pensacola, FL) worn on the nondominant wrist. Wrist-worn accelerometers have been used to monitor sleep in elite athletes[26] and they are validated against polysomnography.[27] Data were analyzed using ActiLife Pro software (v6.13.3; ActiGraph, LLC). Wrist-worn accelerometers can estimate TST (total amount of sleep obtained); time in bed (time between lying down until getting up the next day); wake-up time (time between the last min of sleep and getting up from bed); sleep onset time (time of the first epoch of sleep between time of trying to initiate sleep and time at wake-up); wake after sleep onset (number of min awake after sleep onset); sleep fragmentation index (sum of mobility and immobility accesses in 1 min, divided by the number of immobility accesses); latency (time in min attempting to fall asleep); and sleep efficiency (percentage of time in bed that was spent asleep). The sampling frequency was 50 Hz and the epoch of activity counts was 60 seconds. All movements greater than 0.05 *g* were measured, and values outside the range of 3 to 11 Hz were filtered to eliminate gravitational artifacts.[10,28] All sleep variables were determined for each night using the Sadeh algorithm.[29]

Cardiac Autonomic Activity. The "hour-by-hour" method was used to analyze the cardiac autonomic activity during night sleep.[6,10] This method divides overnight sleep into consecutive 1-hour periods for the cardiac autonomic activity calculations (Kubios HRV 3.0.0 software; Kubios Oy, Kuopio, Finland). In this analysis, a total of 6 periods were analyzed per night sleep, as 6 hours was the minimum amount of sleep recorded.

Heart-rate monitors (Firstbeat Bodyguard2; Firstbeat Technologies) were used during sleep. This device has been validated against standard electrocardiogram equipment to detect heart beats.[30] RR interval data were downloaded into cooperative software (Firstbeat Sports Server). Ectopic beats were automatically removed and replaced with interpolated adjacent RR interval values using a low filter, as described by Tarvainen et al.[31] The RR intervals were analyzed using time and frequency domains, and nonlinear techniques[32] were analyzed using Kubios HRV, 3.0.0 software (Kubios Oy). In addition, to reduce any potential nonuniformity or skewness in HRV, data were log-transformed by taking the natural logarithm (ln) before conducting any statistical analyses.[33] Time domain measures included mean RR interval, mean HR, square root of the mean of the sum of the squares of differences between adjacent NN intervals (RMSSD), and SD of the R–R intervals. RR intervals were also used to produce the Poincaré plot SD_1 (representing the short-term beat-to-beat variability) and SD_2 (representing the long-term beat-to-beat variability) values.[33] Fast Fourier transform (Welch's periodogram: 300-s window with 50% overlap)[32] was used to obtain measures of nocturnal cardiac autonomic activity in the frequency domain, considering both LF (0.004–0.15 Hz) and HF (0.15–0.4 Hz) indices.[32] For frequency analyses, RR trend components were removed using an advanced smoothness prior approach, with a smoothing parameter of $\lambda = 500$, which corresponds to a cutoff frequency of 0.035 Hz.[32] The LF/HF ratio was calculated from nontransformed LF and HF data.

Statistical Analysis

The results are presented as mean (SD). All data sets were assessed for normal distribution using the Shapiro–Wilk test. Actigraphy

variables were compared between pooled TD and RD using paired-sample t tests. The ln transformation was used with time and frequency domains and Poincaré plot variables of cardiac autonomic activity. Nocturnal cardiac autonomic activity variables (for the "hour-by-hour" method) were compared between TD and RD; training load and subjective well-being variables were compared between training sessions, using 2-factor analysis of variance with repeated measures and Bonferroni-corrected paired sample t tests. The 2-factor analysis of variance's effect size (with corresponding 95% confidence intervals) for the nocturnal cardiac autonomic activity, training load, and subjective well-being variables were calculated using partial eta-squared (η_p^2) and interpreted using the following thresholds: small (.01–.05), medium (.06–.13), and large (>.14). The magnitudes of effects (with corresponding 95% confidence intervals) for the actigraphy variables were qualitatively interpreted using the following thresholds: <0.2, trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; 1.2 to 2.0, large; 2.0 to 4.0, very large; and >4.0, nearly perfect.[34] The intrasubject and intersubject coefficient of variation (CV) for TST was calculated to quantify the respective variability levels across days and individuals during the observation period. Statistical significance was set at $P < .05$.

Results

Training-Load Variables

Figure 1 shows sRPE, TRIMP, HR_{ex} (%HR_{peak}), and subjective well-being ratings during TD. Significant differences between TD were found in sRPE (193.3 [60.2] to 442.8 [159.8] a.u.; $F_{3,67} = 15.945$; $\eta_p^2 = .484$ [.28–.58], large effect; $P < .001$), HR_{ex} (%HR_{peak}) (70.5 [3.3] to 75.8 [4.3]; $F_{4,68} = 6.432$; $\eta_p^2 = .274$ [.06–.33], large effect; $P < .001$), and TRIMP (72.9 [18.8] to 138.4 [29.6] a.u.; $F_{4,62} = 32.331$; $\eta_p^2 = .673$ [.001–.16], large effect; $P < .001$). However, no differences in subjective well-being ratings (Hopper Index: 9.9 [2.9] to 12.3 [3.8] a.u.; $F_{4,67} = 3.007$; $\eta_p^2 = .150$ [.001–.27], large effect; $P > .05$) were observed.

Sleep Variables

The actigraphic analysis of sleep after TD and RD are presented in Table 2. A moderate effect of night training on TST was detected. Additionally, TD and RD differed in sleep onset time (moderate effect), wake-up time (small effect), time in bed (small effect), and sleep latency (small effect). No significant differences were found in relation to wake after sleep onset, the sleep fragmentation index, and sleep efficiency ($P > .05$). Within each condition (TD and RD), there were no significant differences in any of the sleep indices ($P > .05$). When pooling together all the TD and RD, the intrasubject and intersubject CVs for TST were 15.0% and 17.5%, respectively.

Cardiac Autonomic Activity Variables

Nocturnal "hour-by-hour" cardiac autonomic activity indices are detailed in Table 3. HR during sleep was higher during TD than RD ($F_{2,32} = 15.956$; $\eta_p^2 = .484$ [.20–.63]), large effect; $P < .001$), but no effects were detected for any HRV variables ($P > .05$). Figure 2 illustrates the lnRMSSD throughout the nights following the smallest (TD7; 72.9 a.u.) and highest (TD4; 138.4 a.u.) values of TRIMP accumulated during TD. No significant TD versus hours interaction effect was detected for the lnRMSSD ($F_{3,49} = 1.385$; $\eta_p^2 = .042$ [.01–.98], small effect; $P > .05$). In addition, the paired comparisons (1H of TD4 vs 1H of TD7) were not meaningful (effect size = 0.091–0.261, trivial to small effects; $P > .05$).

Discussion

The present study evaluated the effects of night soccer training on sleep patterns and overnight cardiac autonomic activity in high-level female athletes. Results showed that night training (resulting in TRIMP = 72.9–138.4 a.u.) disturbed sleep and increased HR, while HRV was not affected. Therefore, the hypothesis of the present study was partially confirmed, demonstrating changes in actigraphic variables and HR, whereas limited effects were found in HRV after night soccer training sessions in semi-professional female athletes.

Healthy adults should accumulate at least 7 hours of sleep per night to prevent cumulative neurobehavioral deficits in daytime performance.[2] In the current study, although players accumulated adequate sleep, a decreased duration of sleep was found following TD compared with RD. In fact, an important finding was the consistent reduction in TST (−34 min) and a delay in sleep onset time (+44 min) following TD compared with RD. It is not easy to compare our results with previous findings as the majority of studies investigated the effects of night matches, and not training sessions, on sleep actigraphy. Nevertheless, a recent study[35] showed that an evening training session and competition (both started at 6:00 PM) also caused a reduction in TST (–45 and −123 min, respectively) compared with a control day, and the delay in bedtime may be caused simply by the timing of the match and training. It seems that late-night match and training start-times are the key factors that could significantly and negatively impact sleep variables in these team-sport players.

Accordingly, sleep onset time and TST in our sample were delayed and reduced, respectively, following night TD, supporting the idea that sleep indices are likely dependent on the scheduling of the training practices.[1] A recent study showed that 52.3% of elite athletes subjectively reported sleep disturbances following a late match or training session.[36] Therefore, the most predictable reason for this could be the bedtime extension caused by the timing of the training session.[1]

Interestingly, the within-player variability (CV = 15.0%) of TST across 16 days of RD and TD was relatively low, which is evidence that even under the constraint imposed by the night training scheduling, the athletes maintained relatively good consistency in sleep habits, probably related to the willingness to recover from the training sessions and other academic/labor activities. Of note, this value was comparable with the between-player variability (CV = 17.5%), which was higher than those calculated in the study by Fullagar et al[11] during TD (CV = 4.7%) and day matches (CV = 4.8%), but lower than in night-match days (CV = 25.2%), among elite soccer players.

Besides reduced sleep duration, differences in sleep latency between TD and RD were observed. Athlete exposure to the bright lights in a stadium may have an impact on sleep (by prolongation of sleep onset).[37] During training sessions, the athletes were exposed to >1200 lux. Factors such as luminance levels, exposure duration, timing, and wavelength of light have an important influence on the alerting response of humans, with bright polychromatic light (≥1000 lux) being sufficient to elicit maximal alerting effects during sleep.[38]

Overnight HRV has been attracting great interest in the assessment of the autonomic nervous system activity and recovery from daily load, due to its noninvasive nature.[6] Nighttime is generally free of events known to affect cardiac autonomic control, such as noise or light. Unfortunately, information on nocturnal HRV after late training practices is very limited. In the current

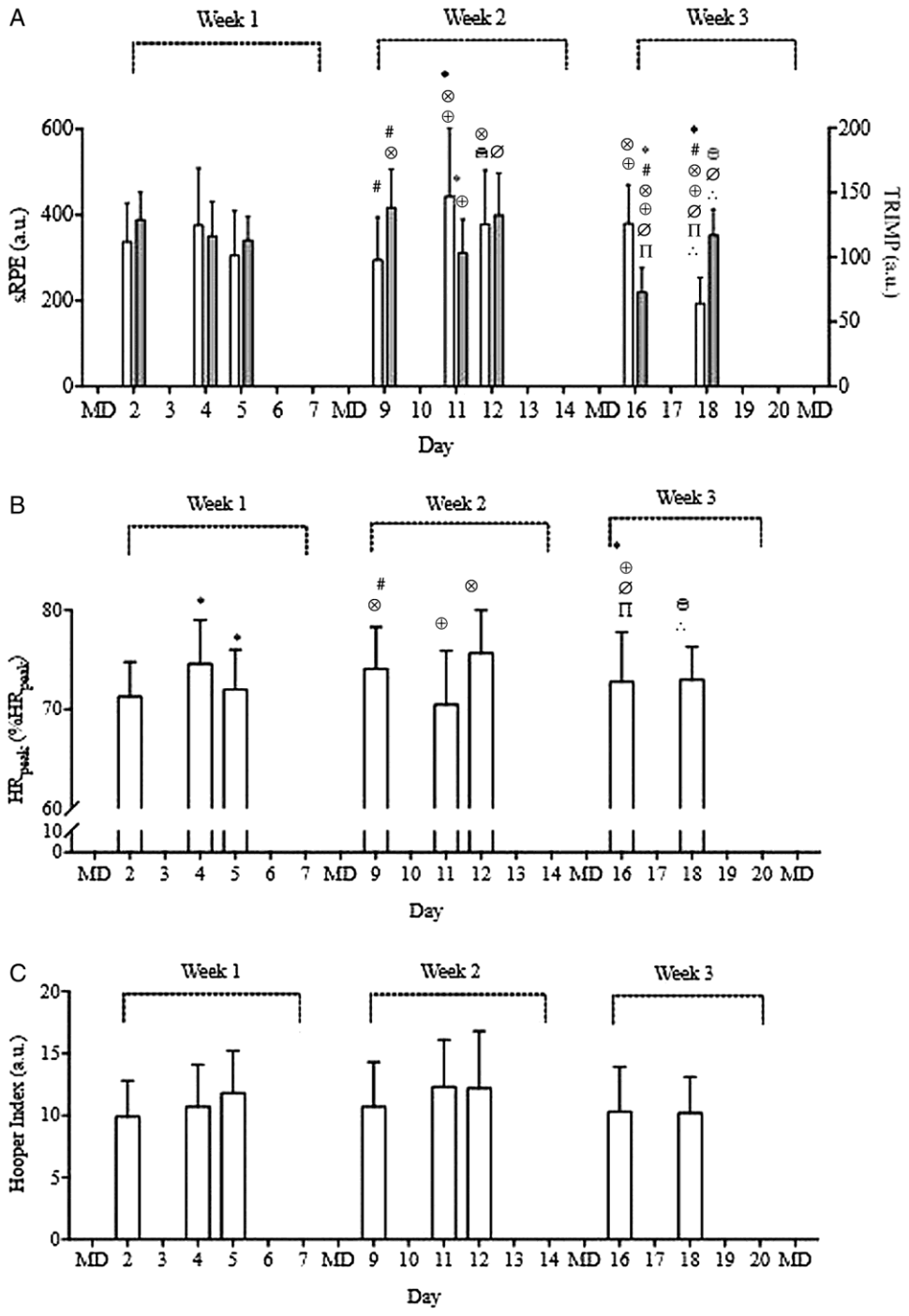


Figure 1 — Internal training load (A and B) and subjective well-being (C) responses during 3 weeks (8 training sessions). (A) sRPE and TRIMP, both are expressed in a.u. (B) HR_{ex}, expressed as $\%HR_{peak}$. (C) Hooper Index, expressed in a.u. Note: Black symbols represent sRPE (A) and HR_{ex} ($\%HR_{peak}$; B) differences, and gray symbols represent TRIMP (A) differences, between training days. a.u. indicates arbitrary units; HR, heart rate; HR_{ex}, average HR during exercise; HR_{peak}, peak HR; $\%HR_{peak}$, percentage relative to the individual HR_{ex}; MD, match day; sRPE, session rating of perceived exertion; TRIMP, training impulse. *Statistically different from day 2 (training 1). #Statistically different from day 4 (training 2). ⊗Statistically different from day 5 (training 3). ⊕Statistically different from day 9 (training 4). ∅Statistically different from day 11 (training 5). ΠStatistically different from day 12 (training 6). ∴Statistically different from day 16 (training 7).

study, no significant changes in HRV were noticed during TD compared with RD. These results are in accordance with a recent study[6] of shorter duration, and employing lower training load. Notably, in the present study, the TD associated with the lowest and highest TRIMP (Figure 2) did not result in different vagally-mediated HRV throughout the sleep hours. The current findings extend the previous results[6] by showing that TRIMP between 72.9 and 138.4 a.u. in night soccer training sessions does not affect

Table 2 Mean, SD, ES Calculations, and 95% CI of Actigraphy Sleep Responses After Training-Day and Rest-Day Nights (N = 18)

	TD	RD	*P*	ES (95% CI)
Sleep-onset time, h:min	00:58 (00:19)	00:14 (00:16)*	<.001	0.802 (0.68–0.94)
Wake-up time, h:min	09:18 (00:54)	09:39 (00:49)*	.016	0.483 (0.26–0.88)
TIB, h:min	08:19 (01:06)	08:50 (00:58)*	.015	0.501 (0.28–0.88)
TST, h:min	07:17 (00:47)	07:51 (00:42)*	.005	0.742 (0.59–0.92)
WASO, min	56 (30)	55 (24)	.978	0.003 (0.001–0.26)
SFI, %	27 (9)	26 (7)	.852	0.021 (0.004–0.93)
SE, %	88 (5)	89 (4)	.102	0.304 (0.07–1.30)
Latency, min	6 (4)	4 (4)*	.045	0.484 (0.23–1.00)

Abbreviations: CI, confidence interval; ES, effect size; RD, rest day; SE, sleep efficiency; SFI, sleep fragmentation index; TD, training day; TIB, time in bed; TST, total sleep time; WASO, wake after sleep onset.
*Significantly different from TD ($P < .05$).

Table 3 Mean, SD, Effect Size Using η_p^2 Calculations, and 95% CI of Cardiac Autonomic Activity (Hour-by-Hour) During Sleep After TD and RD Nights (N = 18)

	1H	2H	3H	4H	5H	6H	*P*	η_p^2 (95% CI)
Heart rate, beats/min								
TD	63 (7)	60 (5)	59 (5)	57 (4)	56 (4)	56 (4)	<.001	.484
RD	57 (6)*	56 (4)*	55 (4)*	55 (4)*	54 (4)*	54 (4)*		(.20–.63)
RR interval, ln(ms)								
TD	6.9 (0.1)	6.9 (0.1)	6.9 (0.9)	6.9 (0.1)	7.0 (0.1)	7.0 (0.1)	<.001	.404
RD	7.0 (0.1)*	7.0 (0.1)*	7.0 (0.9)*	7.0 (0.1)*	7.1 (0.1)*	7.0 (0.1)*		(.15–.55)
RMSSD, ln(ms)								
TD	4.3 (0.4)	4.3 (0.4)	4.3 (0.4)	4.4 (0.4)	4.5 (0.4)	4.5 (0.4)	.105	.112
RD	4.4 (0.3)	4.4 (0.4)	4.4 (0.4)	4.4 (0.4)	4.5 (0.4)	4.5 (0.3)		(.01–.25)
SDNN, ln(ms)								
TD	4.1 (0.3)	4.1 (0.3)	4.2 (0.3)	4.2 (0.3)	4.3 (0.4)	4.3 (0.3)	.454	.051
RD	4.2 (0.3)	4.2 (0.3)	4.2 (0.3)	4.3 (0.3)	4.3 (0.3)	4.3 (0.3)		(.01–.14)
SD_1, ln(ms)								
TD	3.9 (0.4)	4.0 (0.4)	4.0 (0.4)	4.1 (0.4)	4.1 (0.4)	4.1 (0.4)	.709	.020
RD	4.0 (0.4)	4.0 (0.4)	4.0 (0.4)	4.1 (0.4)	4.1 (0.4)	4.2 (0.3)		(.01–.14)
SD_2, ln(ms)								
TD	4.2 (0.3)	4.2 (0.3)	4.3 (0.3)	4.3 (0.3)	4.3 (0.3)	4.4 (0.3)	.592	.036
RD	4.2 (0.3)	4.2 (0.3)	4.3 (0.3)	4.3 (0.3)	4.4 (0.3)	4.4 (0.3)		(.01–.12)
LF, ln(ms^2)								
TD	7.1 (0.6)	7.1 (0.7)	7.2 (0.6)	7.3 (0.6)	7.4 (0.7)	7.5 (0.7)	.523	.043
RD	7.1 (0.7)	7.1 (0.7)	7.3 (0.7)	7.4 (0.7)	7.4 (0.8)	7.5 (0.7)		(.01–.14)
HF, ln(ms^2)								
TD	7.5 (0.7)	7.5 (0.7)	7.6 (0.7)	7.7 (0.7)	7.8 (0.7)	7.8 (0.7)	.333	.064
RD	7.5 (0.6)	7.5 (0.6)	7.6 (0.7)	7.7 (0.7)	7.8 (0.7)	7.8 (0.6)		(.01–.17)
LF:HF								
TD	0.8 (0.5)	0.8 (0.4)	0.9 (0.4)	0.8 (0.4)	0.9 (0.4)	0.9 (0.4)	.152	.097
RD	0.9 (0.4)	0.8 (0.4)	0.9 (0.4)	0.9 (0.3)	0.9 (0.4)	1.0 (0.5)		(.01–.22)

Abbreviations: CI, confidence interval; ES, effect size; HF, high frequency; LF, low frequency; LF:HF, ratio of low- to high-frequency power; NN, normal-to-normal; RD, rest day; RMSSD, square root of the mean of the sum of the squares of differences between adjacent NN intervals; RR interval, variations between consecutive heart beats (beat to beat); η_p^2, partial eta-squared; SD_1, short-term beat-to-beat variability; SD_2, long-term beat-to-beat variability; SDNN, SD of all NN intervals; TD, training day.
Note: All variables were calculated for the whole night's sleeping period.
*Significantly different from TD ($P < .05$).

overnight HRV compared with RD. It remains to be determined whether matches, which are known to result in higher internal load (TRIMP = ~500 a.u.),[17] change sleep HRV in comparison with both investigated situations. Supporting this notion, the perceived well-being (as established by Hooper et al[25]) of the players across the TD did not significantly change (although effect size was large), thus indicating that the amount of training load in the investigated week was well tolerated by the players. These results are in

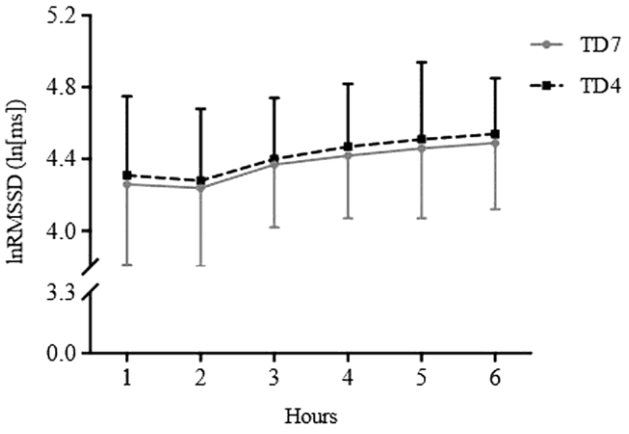


Figure 2 — lnRMSSD activity (hour-by-hour) during sleep throughout the nights after the smallest (TD7) and highest (TD4) values of training impulse accumulated during TD. lnRMSSD indicates natural logarithm of the square root of the mean of the sum of the squares of differences between adjacent normal RR intervals; RR interval, variations between consecutive heart beats (beat to beat); TD, training day.

accordance with previous findings that showed that while wellness measures moderately changed (between 8 and 11, approximately) due to a large increase in mean sRPE (between 290 and 570, approximately), HRV indices only showed a trivial change over 4 consecutive days of monitoring.[39]

In contrast to HRV, HR was elevated after TD during all the sleep hours compared with RD. A possible explanation for this is that exercise close to bedtime has been shown to increase nocturnal body temperature, thermogenic hormones, ventilation, and blood flow, related to the replenishment of energy stores.[40]

Finally, 2 important variables related to late-evening training sessions that could also explain sleep patterns and HRV results are the habitual training time-of-day of the athletes[20] and chronotype[41,42] (which characterizes an individual's circadian rhythmicity). For instance, Rae et al[20] proposed comparing morning and evening time-trial performance, RPE, and mood state of trained swimmers, taking into account chronotype and habitual training time-of-day. The authors found significant diurnal variation in performance when the swimmers were grouped according to habitual training time-of-day. That is, the swimmers who habitually trained in the morning swam faster at 06:30 hours, and those who trained in the evening were faster at 18:30 hours. This suggests that diurnal variation in performance is also related to habitual training time, although it is not clear whether this is due to endogenous factors, or as a result of training time conditioning, or both. In addition, Bonato et al[42] evaluated if the time of day (08.00 AM vs 08.00 PM) and chronotype could influence postexercise autonomic cardiac control in soccer players in relation to an acute session of high-intensity interval training. The authors showed that the circadian typology of the subject determined different autonomic responses during recovery from a demanding training bout performed in the morning only. Despite all this, both variables (habitual training time-of-day and chronotype) were not included in the present study, and we recognize this as a limitation of the study.

This study has some limitations to be considered. Chronotype, habitual training time-of-day, core body temperature, hormones (eg, menstrual cycle), level of light exposure during daytime, and food intake before bedtime were not measured/controlled. Therefore, the mechanisms underlying sleep quantity changes observed after exercise can only be speculated. Moreover, this study was limited by the fact that players were not full-time athletes, and other circumstances of their daily life (eg, job, university) were not considered while comparing sleep and HRV between TD and RD.

Conclusion and Practical Applications

In summary, this study showed changes in actigraphic variables and HR after night soccer training sessions during subsequent sleep. More specifically, high-level female soccer players who engage in soccer training late in the night (after 21 h) dispose of average of 7 hours and 17 minutes of sleep per night. Given that 7 to 9 hours of sleep per night might be required to avoid cumulative deficits in daytime function, it is reasonable to suggest that recovery was not impaired. However, the amount of sleep an athlete dispose might be influenced by the timing of training (~30 min of difference compared with RD). The lack of change in overnight HRV during TD compared with RD indicates that cardiac autonomic homeostasis was not severely disturbed by training sessions conducted at night in high-level female soccer players.

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References

1. Sargent C, Lastella M, Halson SL, Roach GD. The impact of training schedules on the sleep and fatigue of elite athletes. *Chronobiol Int*. 2014;31(10):1160–1168. PubMed ID: 25222347 doi:10.3109/07420528.2014.957306
2. Watson NF, Badr MS, Belenky G, et al. Recommended amount of sleep for a healthy adult: a joint consensus statement of the American Academy of Sleep Medicine and Sleep Research Society. *Sleep*. 2015;38(6):843–844. PubMed ID: 26039963
3. Gupta L, Morgan K, Gilchrist S. Does elite sport degrade sleep quality? A systematic review. *Sports Med*. 2017;47(7):1317–1333. PubMed ID: 27900583 doi:10.1007/s40279-016-0650-6
4. Mah CD, Mah KE, Kezirian EJ, Dement WC. The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep*. 2011;34(7):943–950. PubMed ID: 21731144 doi:10.5665/SLEEP.1132
5. Kolling S, Steinacker JM, Endler S, Ferrauti A, Meyer T, Kellmann M. The longer the better: sleep–wake patterns during preparation of the World Rowing Junior Championships. *Chronobiol Int*. 2016;33(1):73–84. PubMed ID: 26730643 doi:10.3109/07420528.2015.1118384
6. Costa JA, Brito J, Nakamura FY, Oliveira EM, Rebelo AN. Effects of late-night training on "slow-wave sleep episode" and hour-by-hour-derived nocturnal cardiac autonomic activity in female soccer players. *Int J Sports Physiol Perform*. 2018;13(5):638–644. PubMed ID: 29345542 doi:10.1123/ijspp.2017-0681
7. Al Haddad H, Laursen PB, Ahmaidi S, Buchheit M. Nocturnal heart rate variability following supramaximal intermittent exercise. *Int J*

Sports Physiol Perform. 2009;4(4):435–447. PubMed ID: 20029095 doi:10.1123/ijspp.4.4.435
8. Esco MR, Flatt AA, Nakamura FY. Initial weekly HRV response is related to the prospective change in VO_2max in female soccer players. *Int J Sports Med*. 2016;37(6):436–441. PubMed ID: 27042998 doi:10.1055/s-0035-1569342
9. Bricout VA, Dechenaud S, Favre-Juvin A. Analyses of heart rate variability in young soccer players: the effects of sport activity. *Auton Neurosci*. 2010;154(1–2):112–116. PubMed ID: 20061188 doi:10.1016/j.autneu.2009.12.001
10. Myllymaki T, Kyrolainen H, Savolainen K, et al. Effects of vigorous late-night exercise on sleep quality and cardiac autonomic activity. *J Sleep Res*. 2011;20(1, pt 2):146–153. PubMed ID: 20673290 doi:10.1111/j.1365-2869.2010.00874.x
11. Fullagar HH, Skorski S, Duffield R, Julian R, Bartlett J, Meyer T. Impaired sleep and recovery after night matches in elite football players. *J Sports Sci*. 2016;34(14):1333–1339. PubMed ID: 26750446 doi:10.1080/02640414.2015.1135249
12. Sargent C, Halson S, Roach GD. Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. *Eur J Sport Sci*. 2014;14(suppl 1):S310–S315. doi:10.1080/17461391.2012.696711
13. Robey E, Dawson B, Halson S, Gregson W, Goodman C, Eastwood P. Sleep quantity and quality in elite youth soccer players: a pilot study. *Eur J Sport Sci*. 2014;14(5):410–417. PubMed ID: 24093813 doi:10.1080/17461391.2013.843024
14. Fullagar HH, Duffield R, Skorski S, Coutts AJ, Julian R, Meyer T. Sleep and recovery in team sport: current sleep-related issues facing professional team-sport athletes. *Int J Sports Physiol Perform*. 2015;10(8):950–957. PubMed ID: 25756787 doi:10.1123/ijspp.2014-0565
15. Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med*. 2014;44(suppl 2):139–147. doi:10.1007/s40279-014-0253-z
16. Casamichana D, Castellano J, Calleja-Gonzalez J, San Roman J, Castagna C. Relationship between indicators of training load in soccer players. *J Strength Cond Res*. 2013;27(2):369–374. PubMed ID: 22465992 doi:10.1519/JSC.0b013e3182548af1
17. Impellizzeri FM, Rampinini E, Coutts AJ, Sassi A, Marcora SM. Use of RPE-based training load in soccer. *Med Sci Sports Exerc*. 2004;36(6):1042–1047. PubMed ID: 15179175 doi:10.1249/01.MSS.0000128199.23901.2F
18. Flatt AA, Esco MR, Nakamura FY. Association between subjective indicators of recovery status and heart rate variability among Divison-1 sprint-swimmers. *Sports*. 2018;6(3):93. doi:10.3390/sports6030093
19. Werner GG, Ford BQ, Mauss IB, Schabus M, Blechert J, Wilhelm FH. High cardiac vagal control is related to better subjective and objective sleep quality. *Biol Psychol*. 2015;106:79–85. PubMed ID: 25709072 doi:10.1016/j.biopsycho.2015.02.004
20. Rae DE, Stephenson KJ, Roden LC. Factors to consider when assessing diurnal variation in sports performance: the influence of chronotype and habitual training time-of-day. *Eur J Appl Physiol*. 2015;115(6):1339–1349. PubMed ID: 25631930 doi:10.1007/s00421-015-3109-9
21. Vitale JA, Banfi G, Galbiati A, Ferini-Strambi L, La Torre A. Effect of a night game on actigraphy-based sleep quality and perceived recovery in top-level volleyball athletes. *Int J Sports Physiol Perform*. 2019;14(2):265–269. doi:10.1123/ijspp.2018-0194
22. Myllymaki T, Rusko H, Syvaoja H, Juuti T, Kinnunen ML, Kyrolainen H. Effects of exercise intensity and duration on nocturnal heart rate variability and sleep quality. *Eur J Appl Physiol*. 2012;112(3):801–809. PubMed ID: 21667290 doi:10.1007/s00421-011-2034-9
23. Bangsbo J. The physiology of soccer—with special reference to intense intermittent exercise. *Acta Physiol Scand Suppl*. 1994;619:1–155. PubMed ID: 8059610
24. Banister E. Modeling elite athletic performance. In: MacDougall JD, Wenger HA, Green HJ, eds. *Physiological Testing of the High-Performance Athlete*. Champaign, IL: Human Kinetics; 1991:403–424.
25. Hooper SL, Mackinnon LT, Howard A, Gordon RD, Bachmann AW. Markers for monitoring overtraining and recovery. *Med Sci Sports Exerc*. 1995;27(1):106–112. PubMed ID: 7898325 doi:10.1249/00005768-199501000-00019
26. Staunton C, Gordon B, Custovic E, Stanger J, Kingsley M. Sleep patterns and match performance in elite Australian basketball athletes. *J Sci Med Sport*. 2017;20(8):786–789. PubMed ID: 28169152 doi:10.1016/j.jsams.2016.11.016
27. Alsaadi SM, McAuley JH, Hush JM, et al. Assessing sleep disturbance in low back pain: the validity of portable instruments. *PLoS ONE*. 2014;9(4):e95824. PubMed ID: 24763506 doi:10.1371/journal.pone.0095824
28. Paquet J, Kawinska A, Carrier J. Wake detection capacity of actigraphy during sleep. *Sleep*. 2007;30(10):1362–1369. PubMed ID: 17969470 doi:10.1093/sleep/30.10.1362
29. Sadeh A, Sharkey KM, Carskadon MA. Activity-based sleep–wake identification: an empirical test of methodological issues. *Sleep*. 1994;17(3):201–207. PubMed ID: 7939118 doi:10.1093/sleep/17.3.201
30. Parak J, Korhonen I. Accuracy of Firstbeat BodyGuard 2 beat-to-beat heart rate monitor. 2015. https://www.firstbeat.com/app/uploads/2015/10/white_paper_bodyguard2_final.pdf. Accessed May 8, 2017.
31. Tarvainen MP, Niskanen JP, Lipponen JA, Ranta-Aho PO, Karjalainen PA. Kubios HRV—heart rate variability analysis software. *Comput Methods Programs Biomed*. 2014;113(1):210–220. PubMed ID: 24054542 doi:10.1016/j.cmpb.2013.07.024
32. TaskForce. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Circulation*. 1996;93(5):1043–1065. doi:10.1161/01.CIR.93.5.1043
33. Mourot L, Bouhaddi M, Perrey S, et al. Decrease in heart rate variability with overtraining: assessment by the Poincare plot analysis. *Clin Physiol Funct Imaging*. 2004;24(1):10–18. PubMed ID: 14717743 doi:10.1046/j.1475-0961.2003.00523.x
34. Hopkins WG. Statistics in observational studies. In: Verhagen E, van Mechelen W, eds. *Methodology in Sports Injury Research*. Oxford, UK: OUP; 2009:69–81.
35. O'Donnell S, Bird S, Jacobson G, Driller M. Sleep and stress hormone responses to training and competition in elite female athletes. *Eur J Sport Sci*. 2018;18(5):611–618.
36. Juliff LE, Halson SL, Peiffer JJ. Understanding sleep disturbance in athletes prior to important competitions. *J Sci Med Sport*. 2015;18(1):13–18. PubMed ID: 24629327 doi:10.1016/j.jsams.2014.02.007
37. Nedelec M, Halson S, Abaidia AE, Ahmaidi S, Dupont G. Stress, sleep and recovery in elite soccer: a critical review of the literature. *Sports Med*. 2015;45(10):1387–1400. PubMed ID: 26206724 doi:10.1007/s40279-015-0358-z
38. Cajochen C. Alerting effects of light. *Sleep Med Rev*. 2007;11(6):453–464. PubMed ID: 17936041 doi:10.1016/j.smrv.2007.07.009
39. Rabbani A, Baseri MK, Reisi J, Clemente FM, Kargarfard M. Monitoring collegiate soccer players during a congested match schedule: heart rate variability versus subjective wellness measures.

Physiol Behav. 2018;194:527–531. PubMed ID: 29981763 doi:10.1016/j.physbeh.2018.07.001

40. Juliff LE, Peiffer JJ, Halson SL. Night games and sleep: physiological, neuroendocrine, and psychometric mechanisms. *Int J Sports Physiol Perform*. 2018;13(7):867–873. PubMed ID: 29252066 doi:10.1123/ijspp.2016-0809
41. Vitale JA, Bonato M, Galasso L, et al. Sleep quality and high intensity interval training at two different times of day: a crossover study on the influence of the chronotype in male collegiate soccer players. *Chronobiol Int*. 2017;34(2):260–268. PubMed ID: 27906554 doi:10.1080/07420528.2016.1256301
42. Bonato M, Agnello L, Galasso L, et al. Acute modification of cardiac autonomic function of high-intensity interval training in collegiate male soccer players with different chronotype: a crossover study. *J Sports Sci Med*. 2017;16(2):286–294. PubMed ID: 28630583

Study 3

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Sleep patterns and nocturnal cardiac autonomic activity in female athletes are affected by the timing of exercise and match location

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ABSTRACT

The aim of the current study was to analyze the influence of the timing of training and matches, and match location, on sleep pattern and nocturnal cardiac autonomic activity in female soccer players. A total of 17 female soccer players (age: 21.6 ± 2.3 years; mean ± SD) wore wrist actigraph units and heart rate (HR) monitors during night-sleep throughout 18 night-training days (NTD), 18 resting days (RD), and 6 match-days (MD; 3 away-matches [AM] and 3 home-matches [HM]) of the competitive period. Training load was quantified by session rating of perceived exertion (sRPE), heart rate (HR), training impulse (TRIMP), and subjective well-being. In NTD, sleep onset time and total sleep time were significantly impaired compared to MD (+ 1:47 [0:48; 1:55] hours and −1:35 [−1:42; −0:57] hours, respectively; $p < 0.001$; mean difference ± 95% confidence interval [CI]) and RD (+ 1:31 [0:52; 1:49] hours and −1:26 [−1:28; −0:55] hours, respectively; $p < 0.001$). In AM, sleep onset time was delayed compared to HM (+ 0:36 [0:12; 0:44] hours; $p < 0.001$). Sleep latency was higher in NTD compared to RD (+ 4 [2; 5] min; $p < 0.001$), as well as after AM compared to HM (+ 5 [1; 7] min; $p < 0.001$). HR during sleep was significantly increased after NTD and MD compared to RD (+ 4 [1; 5] b.p.m and + 3 [1; 4] b.p.m, respectively; $p < 0.001$). Furthermore, HR variability decreased after NTD and MD compared to RD (e.g., lnRMSSD, −0.09 [−0.18; −0.08] ln[ms] and −0.17 [−0.27; −0.11] ln[ms], respectively; $p < 0.001$). Overall, the time of day for soccer practice (i.e., training at night) and match location (i.e., away matches) may cause disruption in sleep patterns and/or in autonomic cardiac activity in female soccer players. Additionally, playing official matches during the day and training at night may affect nocturnal cardiac autonomic activity by decreasing vagal-related modulation and increasing HR during sleep.

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Accelerometers; heart rate variability; overnight; recovery; women

Introduction

Sleep is recognized as critical for the well-being and performance of athletes, particularly in the competitive season (Fullagar et al. 2016). During congested competitive periods, soccer players follow strict match and training schedules that can reduce sleep duration (Lastella et al. 2015) and impair recovery processes (Vitale et al. 2018), especially when the training and/or matches are performed close to bedtime sleep (Vitale et al. 2018). This fact could be relevant, since in a recent study (Costa et al. 2018) it was observed that female soccer players were habitually trained at very late hours (21:00 h), close to bedtime sleep, due to their daily life commitments (e.g., job, university) which needed to be reconciled with training schedules.

Although there is a general recommendation for ≥7 h of sleep per night to promote optimal health and cognitive performance among adults (Watson et al. 2015), the sleep duration of athletes is frequently less than 7 h (Gupta et al. 2017), and little is known about the sleep characteristics of athletes (Sargent et al. 2014), especially women. Interestingly, female athletes who train and compete late in the evening tend to present more sleep disruptions than male athletes (Mallampalli and Carter 2014).

In a recent study, Nédélec et al. (2018) showed that time in bed and total sleep time were both

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lower after night matches than after training days in elite male soccer players. Night matches disrupted subsequent sleep quantity and quality. Alongside reduced sleeping hours, a significant reduction in perceptual recovery was observed following night-time matches in top-level female and male volleyball athletes (Vitale et al. 2018). Accordingly, reduced sleep following different match-play scenarios (i.e., matches played away or at home) is also of concern for practitioners, given the potential for compromised recovery (Skein et al. 2013). Moreover, due to the time needed to travel, sleep patterns after away-matches (AM) could be more affected than after home-matches (HM) (Fowler et al. 2015).

The effects of physical exercise on sleep have been ascribed to factors such as time of day, chronotype (Bonato et al. 2017a), and training load (Buchheit et al. 2004). Bonato et al. (2017a) evaluated whether the time of day (8.00 a.m. vs 8.00 p.m.) and chronotype (an individual's circadian rhythm) could influence post-exercise autonomic cardiac control in soccer players in relation to an acute session of high-intensity interval training. The authors showed that circadian typology determined different autonomic responses during recovery from a demanding training bout only in the morning. Besides this, Costa et al. (2018) showed, in high-level female soccer players, that night soccer training (9.00 p.m.) elevated HR during sleep but did not affect HRV indices in comparison with resting days. In the referred study, it was speculated that training load undertaken by the players was not high enough to disturb cardiac autonomic function during sleep. Furthermore, other factors could also impair the function of the autonomic nervous system (ANS), such as travelling and away match location (Egan-Shuttler et al. 2018). However, the interaction between these factors and nocturnal HRV has not yet been investigated.

It is currently accepted that overnight sleep measurements over consecutive days are appropriate for tracking the recovery of HRV following high-intensity exercise (Al Haddad et al. 2009). Recently, there has been growing interest in the use of HRV measurements during sleep to evaluate exercise-induced disturbances in body homeostasis, and recovery from daily load (Costa et al. 2018). Moreover, night-time recordings may be of great interest, as sleep constitutes a condition free of external disruptive events. Slow-wave sleep (SWS), corresponding to the deepest stage of sleep involved in recovery processes (Buchheit et al. 2004), could represent an optimal condition for HRV analysis (Brandenberger et al. 2005).

It is noteworthy that there are no longitudinal studies in the literature analyzing objective sleep variables and HRV indices across multiple night-training days, match days, and resting days, as well as in different match locations (i.e., away-matches vs. home-matches) in trained female athletes. Accordingly, the purposes of this study were: (1) to assess sleep patterns and nocturnal cardiac autonomic activity after night training days, match-days, and resting days during a competitive season; and (2) to analyze the influence of match location (home vs. away) on sleep patterns and nocturnal cardiac autonomic activity in female soccer players. It was hypothesized that training at night and playing away matches would disturb sleep patterns and nocturnal cardiac autonomic activity more than resting days and playing home-matches, respectively, in female soccer players.

Materials and methods

Study subjects

A total of 17 female soccer players (age: 21.6 ± 2.3 years; height: 161.5 ± 5.4 cm; body mass: 57.0 ± 6.4 kg; mean ± SD) competing in the first division of the Portuguese soccer league participated in the study. The study design was carefully explained to the subjects, and written informed consent was obtained. Exclusion criteria were: tobacco use, working in a part-time night job, use of medications, and medical conditions contraindicating physical exercise as diagnosed by a sports medicine physician. Players were requested to avoid alcohol and caffeine consumption. All athletes had similar academic and job timetables. The study followed the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of Sports, University of Porto (CEFADE 03.2017).

Study design and protocol

This was a single-group longitudinal study that measured internal training and match load (training and

match impulse [TRIMP], the average HR during exercise [HR_{ex}] as the percentage relative to the individual peak HR [$\%HR_{peak}$], the session-rating of perceived exertion [sRPE]), subjective well-being ratings, sleep and nocturnal cardiac autonomic activity, for 6 weeks (42 days of recordings). This period encompassed three blocks of two consecutive weeks intercepted by two consecutive weeks without recordings (to avoid possible dropouts during the data collection and increase the athletes' adherence to the study procedures), with matches played each Saturday (Table 1). A total of 18 night-training days (NTD), 18 resting days (RD), and 6 day time match days (MD), of which 3 were away-matches (AM) and 3 home-matches (HM), were analyzed. All training sessions started around 9.00 p.m. (21:10 ± 00:21 hours; mean ± SD) and lasted 1:26 ± 00:10 hours (training volume: Week 1, 4:32 ± 00:08 hours; Week 2, 4:28 ± 00:07 hours; Week 3, 4:29 ± 00:10 hours; Week 4, 4:28 ± 00:08 hours; Week 5, 4:26 ± 00:11 hours; Week 6, 4:31 ± 00:05 hours). The training practices proposed by the coach during each session consisted mostly of the following: soccer-specific drills (i.e., skill development and small-sided games [4vs4]), resistance training (whole-body workouts involving power cleans and squats), and scrimmages (10vs10). Matches always started at the same hour, around 3.00 p.m. (15:02 ± 00:09 hours) and lasted 1:33 ± 00:03 hours.

Throughout the study, the participants were asked to follow their normal sleep-wake cycles in their own houses to avoid disturbing their regular habits. It is important to highlight that the time spent travelling (by bus) for each of the three AM was between 30 min and 3 hours (AM_1 ~ 1:30 hours, AM_2 ~ 3:00 hours, and AM_3 ~ 30 min). Each athlete put on the RR interval monitor and wrist-worn accelerometer in their own home, after arriving from training sessions and matches. There was some variation in the time the participants went to bed (bedtime, h: min corresponding to lying down time: NTD, between 00:15 and 00:40 hours, approximately; and RD, MD, AM, and HM between 22:00 and 23:30 hours, approximately). To grant higher ecological validity to the investigation, sleep habits were not constrained by the study procedures. Each morning, the participants were instructed to gently remove the electrodes and accelerometers before leaving their bed.

Table 1. Data collection during 6 weeks (42 days of recordings): three blocks of two consecutive weeks intercepted by two consecutive weeks without recordings . Training load (TL) and well-being were assessed each night-training session and match. Cardiac autonomic activity and actigraphy were assessed during night-sleep, after each training/match day and rest day (RD).

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
2 Consecutive Weeks	TL Well-being Cardiac autonomic activity Actigraphy AM1;HM2	TL Well-being Cardiac autonomic activity Actigraphy NTD1; NTD4	Cardiac autonomic activity Actigraphy RD1; RD4	TL Well-being Cardiac autonomic activity Actigraphy NTD2; NTD5	Cardiac autonomic activity Actigraphy RD2;RD5	TL Well-being Cardiac autonomic activity Actigraphy NTD3; NTD6	Cardiac autonomic activity Actigraphy RD3;RD6
2 Consecutive Weeks							
2 Consecutive Weeks	TL Well-being Cardiac autonomic activity Actigraphy HM2; AM2	TL Well-being Cardiac autonomic activity Actigraphy NTD7; NTD10	Cardiac autonomic activity Actigraphy RD7; RD10	TL Well-being Cardiac autonomic activity Actigraphy NTD8; NTD11	Cardiac autonomic activity Actigraphy RD8; RD11	TL Well-being Cardiac autonomic activity Actigraphy NTD9; NTD12	Cardiac autonomic activity Actigraphy RD9; RD12
2 Consecutive Weeks							
2 Consecutive Weeks	TL Well-being Cardiac autonomic activity Actigraphy HM3; AM3	TL Well-being Cardiac autonomic activity Actigraphy NTD13; NTD16	Cardiac autonomic activity Actigraphy RD13; RD16	TL Well-being Cardiac autonomic activity Actigraphy NTD14; NTD17	Cardiac autonomic activity Actigraphy RD14; RD17	TL Well-being Cardiac autonomic activity Actigraphy NTD15; NTD18	Cardiac autonomic activity Actigraphy RD15; RD18

Descriptions: NTD, night-training day; AM, away-matches; HM, home-matches

One week before starting data collection, the athletes completed a Yo-Yo Intermittent Endurance Test-level 2 (YY-IET2) (Bangsbo 1994). The distance covered and peak HR (HR_{peak}) were recorded.

During the 5 weeks prior to the study, players were familiarized with the devices used to avoid training and match activities or sleep pattern being disturbed by the equipment. All training sessions and matches (AM and HM) were performed on an outdoor artificial turf pitch, which was the usual training and match venue of the investigated team. During a 90-min night-training session, the participants were exposed to >1200 lux (horizontal luminance—using a photometer head mounted on an optical bench and measured on a 10m x 10m grid within the playing ground; 28 compact quartz metal halide lamps with double-pinch with luminous efficacy 93 lm/W) and 5600 K color temperature [Tk]). Ambient temperature ranged between 16 and 18°C during the day and between 10 and 12°C during the night.

Training and match load

HR data during training sessions and matches were recorded via radio telemetry (Firstbeat Sports, Finland) and exported to Firstbeat Sports Server® software (version 4.7.3.1). The software also calculated the average HR_{ex}, expressed in absolute values (beats per min [bpm]), and $\%HR_{peak}$.

TRIMP was calculated as proposed by Banister (Banister 1991): $TRIMP = T\times[(HR_{ex}-HR_{rest})/(HR_{peak}-HR_{rest})]\times 0.86e^{1.67([HRex-HRrest)/(HRpeak-HRrest)]}$; where T is the duration of the workout in minutes; HR_{ex} the average HR during exercise; HR_{rest} the average HR during rest, measured during 5 min of seated rest before starting each training session and match during the study period; HR_{peak} is determined as the highest value reached during the YY-IET 2 test, and e ~ 2.718.

The RPE was obtained approximately 15–30 min after each training session and match. sRPE was determined using the multiplication of the CR-10 scale by the duration of the training session (Foster et al. 2001).

Approximately 15 min before each training session and match, the players completed a questionnaire involving well-being ratings relative to fatigue, stress level, DOMS, and sleep quality/disorders (scales of 1–7; (Hooper et al. 1995)). The Hooper's Index is the summation of these four ratings.

Actigraphy

Sleep was assessed using 3-axial accelerometers (Actigraph LLC wGT3X-BT, Pensacola, USA) worn on the non-dominant wrist. Wrist-worn accelerometers have been used to monitor sleep in elite athletes (Staunton et al. 2017), and validated against polysomnography (PSG; (Alsaadi et al. 2014)). Data were analyzed using ActiLife LLC Pro software v6.13.3, Pensacola, USA. Wrist-worn accelerometers can estimate total sleep time, time in bed, wake up time, sleep onset time, waking after sleep onset, sleep fragmentation index, latency, and sleep efficiency. The sampling frequency was 50 Hz and the epoch of activity counts was 60 s (Sadeh et al. 1994). All sleep variables were determined every night using the Sadeh algorithm (Sadeh et al. 1994) .

Cardiac autonomic activity

The SWSE method was used to analyze the cardiac autonomic activity during night-sleep (Brandenberger et al. 2005). This method records 10 minutes of normal RR intervals, considering the criteria proposed by Brandenberger et al., (Brandenberger et al. 2005), using Kubios HRV 3.0.0® software (Kubios Oy, Kuopio, Finland). HR monitors (Firstbeat Bodyguard2®, Firstbeat Technologies, Finland) were used during sleep. The device has been validated against standard ECG equipment to detect heartbeats (Parak and Korhonen 2015). The RR intervals were analyzed by means of time and frequency domains, and nonlinear techniques (TaskForce 1996), using Kubios HRV, 3.0.0® software (Kubios Oy, Kuopio, Finland). In addition, to reduce any potential non-uniformity or skewness in HRV, data were log-transformed by taking the natural logarithm (ln) before conducting any statistical analyses (Mourot et al. 2004).

Statistical analysis

The results are presented as mean ± SD. Sample distribution was tested using the Shapiro–Wilk

test. Natural logarithm transformation was used with time and frequency domains, and Poincaré plot variables of cardiac autonomic activity. A linear mixed model analysis was performed to examine differences in cardiac autonomic activity, sleep indices, training and match load, and subjective well-being variables between the NTD, RD, and MD conditions, as well as between the different match locations (AM vs. HM). An α-level of 0.05 was set as the level of significance for statistical comparisons. In all analysis, match location was included as a fixed effect and player identity as the random effect. Furthermore, the recommended variance-covariance structure among all models used was selected according to the smallest Akaike Information Criterion assessment (Akaike 1974), based on the Restricted Maximum Likelihood method. Pairwise comparisons (Bonferroni) showed the mean difference between the conditions.

Magnitudes of the standardized effects were calculated to evaluate the true effects with respect to the smallest worthwhile difference for sleep, HRV, training load, and well-being variables, using Cohen's *d* effect size (ES) (Hopkins 2009). Threshold values for Cohen's effect size statistics were >0.2 (small), >0.6 (moderate), and >1.2 (large) with corresponding 95% confidence intervals (CI) (Hopkins 2009). Where the chance of benefit and harm were both calculated, a qualitative descriptor was assigned to the following quantitative chances of effect: 0.5–5.0%: very unlikely; 5–25%: unlikely; 25–75%: possibly; 75–95% likely; 95.0–99.5%: very likely; > 99.5%: most likely (Hopkins 2009).

Results

Training and match variables

The sRPE, HR_{ex}, TRIMP, and well-being collected during training sessions and matches are presented in Figure 1.

sRPE was significantly higher after MD compared to NTD (574.9 ± 51.5 a.u. vs. 326.1 ± 33.4 a.u.; mean± SD; $p< 0.001$) and after AM compared to HM (631.7 ± 99.7 a.u. vs. 574.9 ± 51.5 a.u; $p< 0.001$; Figure 1a). Magnitude-based inferences indicated a *most likely positive* effect for sRPE (+ 251.4 a.u.) after MD compared to NTD (ES = 5.71 [3.21;5.87] effect size [95% CI]) and a *possibly positive* effect for sRPE (+ 119.2 a.u.) after AM compared to HM (ES = 0.68 [0.54; 0.97).

TRIMP was significantly higher after MD compared to NTD (302.4 ± 36.9 a.u vs. 192.8 ± 21.4 a.u. $p< 0.001$; Figure 1a). A *most likely positive* effect was observed for TRIMP (+ 109.6a.u.) after MD compared to NTD (ES = 3.42 [2.12; 3.58]).

HR_{ex} ($\%HR_{peak}$) was significantly higher after MD compared to NTD (83 ± 4% vs. 74 ± 2.9% $p< 0.001$; Figure 1b). There was a *most likely positive* effect for HR_{ex} (+ 9%) after MD compared to NTD (ES = 2.32 [1.89; 2.86]).

No effects were detected when comparing NTD vs.MD and AM vs. HM with regards to well-being (Hooper Index; Figure 1c; $p> 0.05$).

Sleep variables

All sleep variables are presented in Table 2, with corresponding mean difference, effect size, magnitude, and qualitative descriptors for sleep onset time, wake up time, TIB, TST, WASO, SFI, SE, and latency.

Sleep onset time was significantly delayed after NTD compared to MD (+ 1:47 hours; ES = 5.45 [2.04; 5.57]; $p< 0.001$). Moreover, TST was significantly reduced after NTD compared to MD (−1:35 hours; ES = −2.86 [−3.15; −2.09]; $p< 0.001$), and latency was significantly decreased after NTD compared to MD (−3 min; ES = −1.51 [−1.65; −1.11]; $p< 0.001$).

Sleep onset time was significantly delayed after NTD compared to RD (+ 1:31 hours; ES = 3.26 [1.02; 3.42]; $p< 0.001$). Moreover, TST was significantly reduced after NTD compared to RD (−1:26 hours; ES = −2.69 [−3.05; −1.87]; $p< 0.001$), and latency was significantly increased after NTD compare to RD (+ 4 min; ES = 2.21 [1.62; 2.43]; $p < 0.001$).

No difference in sleep onset time was observed between MD and RD ($p> 0.32$). However, latency was significantly increased after MD compared to RD (+ 7 min; ES = 4.34 [1.82; 4.94]; $p< 0.001$).

Sleep onset time was significantly delayed after AM compared to HM (+ 36 min; ES = 1.66 [0.80; 2.01]; $p< 0.001$). Moreover, latency was significantly

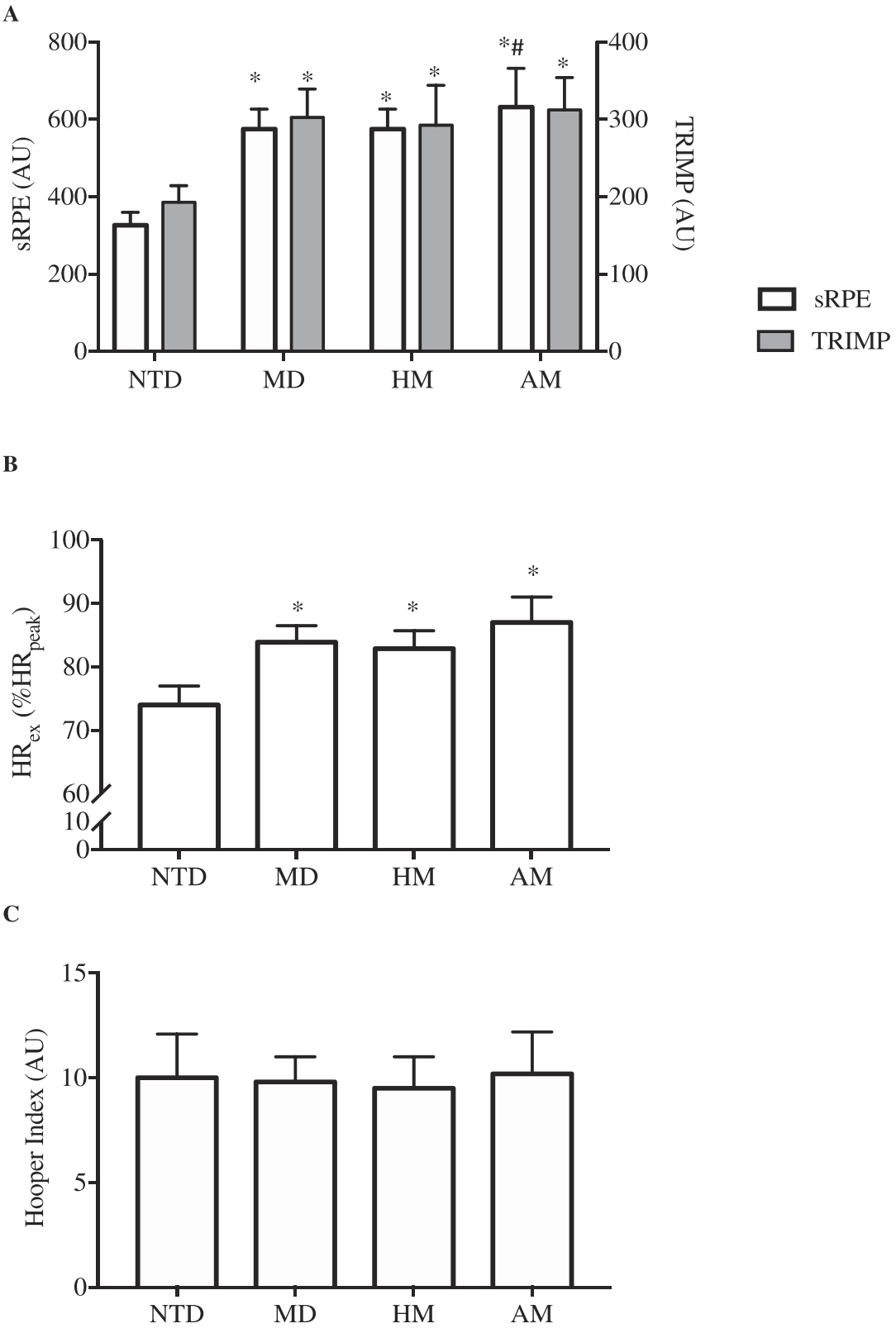


Figure 1. Internal training load (a and b) and subjective well-being (c) responses after night-training day (NTD), match-day (MD), away-match (AM), and home-match (HM) during six weeks of the competitive in-season period. Values are mean± SD.

(a): sRPE, session rating of perceived exertion, and TRIMP, training impulse; both are expressed in arbitrary units (AU). (b): HR_{ex}, the average HR during exercise, expressed as the percentage relative to the individual peak HR ($\%HR_{peak}$). (c): Hooper index; expressed in arbitrary units (AU).* Statistically different from NTD ($p< 0.05$); # Statistically different from HM ($p< 0.05$).

Table 2. Mean ± SD, mean differences and effect sizes for the actigraphy sleep responses during sleep between night-training days (18 days), rest days (18 days), and match-days (6 days) as well as differences between away-matches (3 days) and home-matches (3 days) in female soccer players throughout six weeks of the competitive period. The data are reported as mean difference (95% CI: confidence interval), effect size (95% CI), magnitude, and qualitative descriptor.

	NTD vs. MD	NTD vs. RD	MD vs. RD	AM vs. HM
Sleep onset time				
Mean ± SD(h:min)	00:38 ± 0:07 vs. 22:51 ± 0:15[a]	00:38 ± 0:07 vs. 23:07 ± 0:12[a]	22:51 ± 0:15 vs. 23:07 ± 0:12	23:09 ± 0:15[a] vs.22:33 ± 0:26[a,b,c]
Mean difference (h:min)	1:47(0:48; 1:55)	1:31(0:52; 1:49)	−0:16(−0:42; −0:12)	0:36(0:12; 0:44)
Effect size	5.45(2.04; 5.57)	3.26(1.02; 3.42)	−1.02(−1.42; −0.32)	1.66(0.80; 2.01)
Magnitude	Large	Large	Moderate	Large
Qualitative descriptor	Most likely positive	Most likely positive	Very likely negative	Most likely positive
Wake up time				
Mean ± SD(h:min)	8:34 ± 0:10 vs. 9:22 ± 0:12[a]	8:34 ± 0:10 vs.8:44 ± 0.09	9:22 ± 0:12[b] vs. 8:44 ± 0.09	9:32 ± 0:14[a,b] vs. 9:21 ± 0:19[a,b]
Mean difference (h:min)	−0:48(−0:51; −0:23)	−0:10(−0:28; −0:06)	0:38(0:21; 0:56)	0:11(0:06; 0:31)
Effect size	−3.77(−3.81; −1.62)	−0.85(−0.98; −0.25)	3.19(1.78; 3.31)	0.60(0.43; 0.86)
Magnitude	Large	Moderate	Large	Moderate
Qualitative descriptor	Most likely negative	Most likely negative	Most likely positive	Possibly positive
TIB				
Mean ± SD(h:min)	8:14 ± 0:18 vs.9:54 ± 0:14[a]	8:14 ± 0:18 vs. 9:42 ± 0:21[a]	9:54 ± 0:14 vs. 9:42 ± 0:21	9:56 ± 0:12[a] vs.9:58 ± 0:19[a]
Mean difference (h:min)	−1:40(−1:52; −0:38)	−1:28(−1:37; −0:58)	0:12(0:05; 0:23)	−0:02(−0:17; −0:01)
Effect size	−2.32(−2.67; −1.08)	−1.85(−2.07; −1.12)	0.41(0.17; 0.67)	−0.19(−0.52; −0.11)
Magnitude	Large	Large	Small	Small
Qualitative descriptor	Most likely negative	Most likely negative	Possibly positive	Possibly negative
TST				
Mean ± SD(h:min)	7:09 ± 0:28 vs. 8:44 ± 0:36[a]	7:09 ± 0:28 vs.8:35 ± 0:33[a]	8:44 ± 0:36 vs. 8:35 ± 0:33	9:00 ± 0:58[a] vs. 8:59 ± 0:53[a]
Mean difference(h:min)	−1:35(−1:42; −0:57)	−1:26(−1:28; −0:55)	0:09(0:04; 0:18)	0:01(0.01; 0:04)
Effect size	−2.86(−3.15; −2.09)	−2.69(−3.05; −1.87)	0.26(0.20; 0.42)	0.60(0.23; 0.81)
Magnitude	Large	Large	Small	Moderate
Qualitative descriptor	Most likely negative	Most likely negative	Possibly positive	Possibly positive
WASO				
Mean ± SD(min)	37 ± 12 vs. 47 ± 8	37 ± 12 vs. 44 ± 14	47 ± 8vs.44 ± 14	48 ± 11 vs. 40 ± 10
Mean difference (min)	−10(−23; −7)	−7(−18; −3)	3(2; 11)	8(5; 12)
Effect size	−1.08(−1.65; −0:58)	−0.41(−0.58; −0.19)	0.43(0.25; 0.83)	0.71(0.54; 0.81)
Magnitude	Moderate	Small	Small	Moderate
Qualitative descriptor	Very likely negative	Possibly negative	Possibly positive	Likely positive
SFI				
Mean ± SD(%)	25 ± 7 vs.25 ± 5	25 ± 7 vs. 26 ± 7	25 ± 5 vs. 26 ± 7	24 ± 9 vs. 28 ± 8
Mean difference (%)	−0.34(−8.31; −0.17)	−1.12(−6.01; −0.53)	−0.76(−8.28; −0.32)	−3.23(−3.52; −2.12)
Effect size	−0.12(−0.07; −0.92)	−0.17(−0.67; −0.10)	−0.07(−0.43; −0.02)	−2.30(−2.83; −1.03)
Magnitude	Small	Small	Small	Small
Qualitative descriptor	Possibly negative	Possibly negative	Possibly negative	Most likely negative
SE				

(*Continued*)

Table 2. (Continued).

	NTD vs. MD	NTD vs. RD	MD vs. RD	AM vs. HM
Mean ± SD(%)	90 ± 4 vs. 89 ± 4	90 ± 4 vs. 91 ± 3	89 ± 4 vs. 91 ± 3	88 ± 6 vs. 89 ± 3
Mean difference (%)	0.81(4.32; 0.65)	−0.67(−1.76; −0.44)	−1.76(−4.12; −1.31)	−0.70(−4.46; −0.34)
Effect size	0.33(0.26; 0.56)	−0.28(−0.96; −0.12)	−0.39(−0.88; −0.24)	−0.83(−0.97; −0.72)
Magnitude	Small	Small	Small	Moderate
Qualitative descriptor	Possibly positive	Possibly negative	Possibly negative	Likely negative
Latency				
Mean ± SD(min)	8 ± 2 vs.11 ± 2[a]	8 ± 2 vs.4 ± 2[a]	11 ± 2[b]vs.4 ± 2	14 ± 3[a,b]vs.9 ± 2[a,b,c]
Mean difference (min)	−3(−4; −1)	4(2; 5)	7(2; 8)	5(1; 7)
Effect size	−1.51(−1.65; −1.11)	2.21(1.62; 2.43)	4.34(1.82; 4.94)	1.54(1.07; 1.67)
Magnitude	Large	Large	Large	Large
Qualitative descriptor	Most likely negative	Most likely positive	Most likely positive	Most likely positive

Descriptions: NTD, night-training day; RD, rest day; MD, match-days; AM, away-matches; HM, home-matches; sleep onset time (time of the first epoch of sleep between time of trying to initiate sleep and time of wake up); wake up time (time between the last minute of sleep and getting up from bed); time in bed (TIB, time between lying down until getting up the next day); total sleep time (TST, total amount of sleep obtained); wake after sleep onset (WASO, amount of time spent awake after sleep has been initiated); sleep fragmentation index (SFI, sum of mobility and immobility accesses in one minute, divided by the number of immobility accesses); sleep efficiency (SE, percentage of time in bed that was spent asleep); latency (time in minutes for attempting to fall asleep). [a]Significantly different from NTD ($p < 0.05$). [b]Significantly different from RD ($p < 0.05$). [c]Significantly different from AM ($p < 0.05$).

increased after AM compared to HM (+ 5 min; ES = 1.54 [1.07; 1.67]; $p < 0.001$).

Cardiac autonomic activity variables

All cardiac autonomic activity variables are presented in Table 3, with corresponding mean difference, effect size, magnitude, and qualitative descriptors for HR, RR, lnSDNN, lnRMSSD, lnSD1, lnSD2, lnLF, lnHF, and HF/LF.

HR was significantly increased after NTD compared to RD (+ 4 b.p.m.; ES = 4.40 [2.81; 4.87]; $p < 0.001$). In addition, significant differences were detected in HRV indices (lnRMSSD, lnSD1, lnSD2, lnHF, lnLF, and HF/LF) after NTD compared to RD ($p \leq 0.01$) (e.g., lnRMSSD was significantly reduced after NTD compared to RD; −0.09ln [ms]; ES = −0.71 [−0.89; −0.47]; $p < 0.01$).

HR was significantly increased after MD compared to RD (+ 3 b.p.m.; ES = 2.56 [1.48; 2.87]; $p < 0.001$). Moreover, significant differences were detected in HRV indices (lnRMSSD, lnSD1, lnHF, lnLF, and HF/LF) after MD compared to RD ($p \leq 0.01$) (e.g., lnRMSSD was significantly reduced after MD compared to RD [−0.17ln[ms]; ES = −0.80 [−0.91; −0.52]; $p < 0.01$).

No differences were observed in HR and HRV indices when comparing AM with HM ($p > 0.41$).

Discussion

To the best of our knowledge, this is the first study to concurrently investigate the impact of night soccer training and evening matches at different locations (home and away) on sleep patterns and cardiac autonomic activity in high-level female athletes. The main findings of the study were that: (1) time of day for soccer practices (i.e., training at night) and match location (i.e., away matches) disturbed sleep patterns; (2) playing official matches during the day and training at night affected nocturnal cardiac autonomic activity by decreasing vagal-related modulation and increasing HR during sleep; and (3) match location did not affect nocturnal cardiac autonomic activity. Therefore, the hypothesis of the present study was partly confirmed, showing that sleep patterns and autonomic cardiac activity were affected by night training compared to resting days and

Table 3. Mean ± SD, mean differences and effect sizes for the cardiac autonomic activity (SWSE method) responses during sleep between night-training days (18 days), rest days (18 days), and match-days (6 days) as well as differences between away-matches (3 days) and home-matches (3 days) in female soccer players throughout six weeks of the competitive period. The data are reported as mean difference (95% CI: confidence interval), effect size (95% CI), magnitude, and qualitative descriptor.

	NTD vs. MD	NTD vs. RD	MD vs. RD	AM vs. HM
HR				
Mean ± SD(bpm)	57 ± 1 vs.56 ± 3	57 ± 1 vs.53 ± 1[a]	56 ± 3[b]vs. 53 ± 1	55 ± 4[b] vs. 57 ± 4[b]
Mean difference(bpm)	1 (1; 4)	4(1; 5)	3(1; 4)	1(1; 3)
Effect size	0.27(0.12; 0.64)	4.40(2.81; 4.87)	2.56(1.48; 2.87)	0.11(0.09;0.78)
Magnitude	Small	Large	Large	Small
Qualitative descriptor	Possibly positive	Most likely positive	Very likely positive	Possibly positive
RR				
Mean ± SD (ln[ms])	6.98 ± 0.02 vs.7.03 ± 0.16	6.98 ± 0.02 vs. 7.05 ± 0.01[a]	7.03 ± 0.16[b] vs. 7.05 ± 0.01	7.08 ± 0.30[b] vs. 6.98 ± 0.07[b]
Mean difference(ln[ms])				
Effect size	−0.05(−0.15; −0.02)	−0.07(−0.22; −0.04)	−0.02(−0.33; −0.01)	0.10(0.07; 0.36)
Magnitude	−0.53(−0.64; −0.31)	−1.52(−1.83; −1.43)	−0.34(−0.97; −0.22)	0.84(0.64; 0.97)
Qualitative descriptor	Small	Large	Small	Moderate
	Possibly negative	Most likely negative	Possibly negative	Possibly positive
RMSSD				
Mean ± SD (ln[ms])	4.35 ± 0.14 vs. 4.27 ± 0.24	4.35 ± 0.14 vs. 4.44 ± 0.17[a]	4.27 ± 0.24[b] vs. 4.44 ± 0.17	4.30 ± 0.33[b] vs. 4.23 ± 0.31[b]
Mean difference(ln[ms])				
Effect size	0.08(0.04; 0.32)	−0.09(−0.18; −0.08)	−0.17(−0.27; −0.11)	0.07(0.04; 0.38)
Magnitude	0.34(0.12; 0.95)	−0.71(−0.89; −0.47)	−0.80(−0.91; −0.52)	0.23(0.20; 0.83)
	Small	Moderate	Moderate	Small
Qualitative descriptor	Possibly positive	Likely negative	Possibly negative	Possibly positive
SDNN				
Mean ± SD (ln[ms])	4.04 ± 0.10 vs. 3.97 ± 0.21	4.04 ± 0.10 vs.4.06 ± 0.12	3.97 ± 0.21 vs.4.06 ± 0.12	3.99 ± 0.28 vs. 3.94 ± 0.26
Mean difference(ln[ms])	0.07(0.05; 0.16)	−0.02(−0.17; −0.01)	−0.09(−0.12; −0.06)	0.05(0.02; 0.42)
Effect size	0.52(0.29; 0.87)	−0.20(−0.67; −0.11)	−0.56(−0.99; −0.45)	0.10(0.09; 0.81)
Magnitude	Small	Small	Small	Small
Qualitative descriptor	Possibly positive	Possibly negative	Likely negative	Possibly positive
SD1				
Mean ± SD (ln[ms])	4.00 ± 0.14 vs. 3.92 ± 0.24	4.00 ± 0.14 vs.4.09 ± 0.17[a]	3.92 ± 0.24[b] vs.4.09 ± 0.17	3.96 ± 0.33[b] vs. 3.89 ± 0.31[b]
Mean difference(ln[ms])	0.08(0.05; 0.28)	−0.09(−0.23; −0.07)	−0.17(−0.32; −0.12)	0.07(0.03; 0.21)
Effect size	0.46(0.28; 0.96)	−0.61(−0.87; −0.46)	−0.85(−0.91; −0.58)	0.23(0.12; 0.81)
Magnitude	Small	Moderate	Moderate	Small
Qualitative descriptor	Possibly positive	Likely negative	Likely negative	Possibly positive
SD2				
Mean ± SD (ln[ms])	4.03 ± 0.07 vs. 3.98 ± 0.19	4.03 ± 0.07 vs. 3.98 ± 0.09[a]	3.98 ± 0.19 vs. 3.98 ± 0.09	3.99 ± 0.26vs. 3.97 ± 0.23
Mean difference(ln[ms])	0.05(0.02; 0.19)	0.05(0.01; 0.22)	0.01(0.01; 0.43)	0.02(0.01; 0.18)
Effect size	0.42(0.36; 0.87)	0.67(0.41; 0.91)	0.08(0.03; 0.61)	0.04(0.03; 0.31)
Magnitude	Small	Moderate	Small	Small
Qualitative descriptor	Possibly positive	Likely positive	Possibly positive	Possibly positive
LF				
Mean ± SD (ln[ms^2])	6.45 ± 0.09 vs.6.43 ± 0.48	6.45 ± 0.09 vs. 6.24 ± 0.10[a]	6.43 ± 0.48[b]vs. 6.24 ± 0.10	6.39 ± 0.63[b]vs. 6.47 ± 0.52[b]
Mean difference(ln[ms^2])	0.02(0.01; 0.42)	0.22(0.01; 0.32)	0.19(0.11; 0.36)	−0.08(−0.30; −0.06)
Effect size	0.15(0.11; 0.92)	1.90(0.61; 1.93)	0.99(0.85; 1.02)	−0.16(−0.41; −0.10)
Magnitude	Small	Large	Moderate	Small

(*Continued*)

Table 3. (Continued).

	NTD vs. MD	NTD vs. RD	MD vs. RD	AM vs. HM
Qualitative descriptor	Possibly positive	Most likely positive	Likely positive	Possibly negative
HF				
Mean ± SD (ln[ms^2])	7.56 ± 0.24 vs. 7.41 ± 0.46	7.56 ± 0.24 vs. 7.68 ± 0.32[a]	7.41 ± 0.46[b]vs. 7.68 ± 0.32	7.46 ± 0.64[b]vs. 7.35 ± 0.59[b]
Mean difference(ln[ms^2])	0.15(0.09; 0.31)	−0.12(−0.58; −0.10)	−0.27(−0.51; −0.39)	0.11(0.08; 0.20)
Effect size	0.53(0.46; 0.67)	−0.42(−0.48; −0.35)	−0.73(−0.81; −0.65)	0.15(0.09; 0.41)
Magnitude	Small	Small	Moderate	Small
Qualitative descriptor	Possibly positive	Possibly negative	Likely negative	Possibly positive
LF/HF				
Mean ± SD	0.56 ± 0.12 vs. 0.53 ± 0.24	0.56 ± 0.12 vs. 0.40 ± 0.11[a]	0.53 ± 0.24[b]vs. 0.40 ± 0.11	0.46 ± 0.37[b]vs. 0.60 0.32[b]
Mean difference	0.03(0.01; 0.21)	0.16(0.09; 0.19)	0.12(0.11; 0.31)	−0.14(−0.34; −0.10)
Effect size	0.46(0.12; 0.56)	1.35(0.14; 1.41)	0.66(0.56; 0.77)	−0.69(−0.77; −0.58)
Magnitude	Small	Large	Moderate	Moderate
Qualitative descriptor	Possibly positive	Most likely positive	Likely positive	Likely negative

Descriptions: NTD, night-training day; RD, rest day; MD, match-days; AM, away-matches; HM, home-matches; RR interval, variations between consecutive heart beats (beat to beat); RMSSD, square root of the mean of the sum of the squares of differences between adjacent NN intervals; SDNN, standard deviation of all NN interval; SD1, short-term beat-to-beat variability; SD2, long-term beat-to-beat variability; LF, low frequency; HF, high frequency; LF/HF, ratio of the low- to high-frequency power. [a] Significantly different from NTD ($p < 0.05$). [b] Significantly different from RD ($p < 0.05$).

match days, while away matches only disrupted sleep patterns compared to home-matches, in female soccer players.

In the current study, although players accumulated adequate sleep (≥7h), a decreased duration of sleep was observed following NTD. In fact, an important finding was the consistent reduction in TST and a delay in sleep onset time following NTD. Juliff et al. (2015) showed that sleep indices were likely dependent on the scheduling of practices of the particular sport. The study also showed that 52% of elite athletes subjectively reported sleep disturbances following a late match or training session. The results of the present study are in accordance with recent studies showing that players presented sleep duration within the appropriate healthy range on TD and MD concluded before 6 p.m., but slept significantly less with later bed times after training sessions/matches with a start time later than 6 p.m. (Fullagar et al. 2016; Nédélec et al. 2018). Furthermore, Vitale et al. (2018) showed that sleep quantity and quality were lower during the night immediately following a night-match compared to previous or subsequent nights, in both female and male athletes. Thus, the most predictable reason for the results observed in the present study could be the scheduling of the training session. Hence, it remains to be determined whether night-time fixtures can also severely disturb sleep in female soccer players, when they are used to training at this time of the day (as are the players involved in the current study).

Besides reduced sleep duration, latency was negatively affected after NTD. A large epidemiological survey reported that 24% of respondents perceived difficulty in initiating sleep after late-evening exercise compared to 7% after early evening exercise (Vuori et al. 1988). These results suggest that late-evening exercise can impose a high risk of obstructing falling asleep at night.

Recent studies investigating the differences in sleep behaviors among soccer players have identified several potential chronic and acute causes of sleep disturbance (Vitale et al. 2017a). One possible explanation for the findings observed when comparing night exercise with day exercise and RD could be the athlete's exposure to stadia bright light. Light exposure may have an impact on sleep by extending sleep onset, reducing TST, and augmenting latency (Nedelec et al. 2015). In the current study, the athletes

were exposed to >1200 lux during NTD. Factors such as luminance levels, exposure duration, and timing and wavelength of light have an important influence on the alerting response of humans, with bright polychromatic light (≥1000 lux) being sufficient to elicit maximal alerting effects (Cajochen 2007). Another possible explanation for the findings comparing night training sessions and official matches played during the day with RD could be the complexity of physiological changes acutely induced by exercise (e.g., increase in thermogenic hormones and elevation of body temperature and HR (Borsheim and Bahr 2003)). Exercise before bedtime increases nocturnal body temperature (O'Connor et al. 1998), which may explain the observed increase in HR during sleeping hours following NTD and MD. Moreover, the effect of exercise on sleep disturbance may be related to the delay in reactivation of parasympathetic activity following exercise, leading to persistently high HR at bedtime, lasting for several hours (Costa et al. 2018). In fact, one important factor that could be related to HRV and sleep pattern changes is chronotype (Bonato et al. 2017a; Vitale et al. 2017a). In particular Bonato et al. (2017a) showed that individuals classified as evening-types (as determined using the Morningness-Eveningness Questionnaire) presented higher HR during morning training due to significant parasympathetic withdrawal, with sympathetic predominance at rest and before exercise. Even more interestingly, this variable (chronotype) could be related to changes in muscle physiology and psychology (e.g. as cortisol and mood, respectively) (Vitale and Weydahl 2017). For example, evening-types showed a higher morning peak of salivary cortisol respect to morning-types when performing a high-intensity interval exercise early in the morning and produced higher salivary cortisol concentrations after the cessation of the exercise (Bonato et al. 2017b). However, chronotype classification was not included in the present study, which should be highlighted as an important limitation of the study.

In the present study, the training load imposed on the players appeared to be sufficient to cause a significant impact on HRV during SWSE. In fact, soccer practices significantly decreased RMSSD and HF, both of which are accepted as markers of cardiac parasympathetic activity (Camm et al. 1996). Moreover, the training load measured in NTD and MD in the current study was higher compared to values detected in a previous study (Costa et al. 2018), in which the cardiac autonomic homeostasis of female soccer players was not disturbed by night-training sessions with accumulation of TRIMP of ~70–140 AU. Thus, it could be speculated that the training loads of training sessions and matches imposed on the players in the current study were high enough to promote significant changes in vagal activity, expressed through the increase in HR during sleep. This topic deserves future investigation to better elucidate the relationship between training/match load and cardiac autonomic disturbance during sleep. Nonetheless, it is suggested that training and match loads in the ranges observed herein may induce significant changes in HRV during post-exercise night sleep in high level female soccer players. Supporting this notion, and according to the classification of physical activity intensity proposed by the ACSM (Pollock et al. 1998), the intensity of exercise during NTD (74% HR_{peak}) and MD (84% HR_{peak}) observed in the current study are classified as hard (70–89% HR_{peak}). This agrees with studies showing that high-intensity exercise reduces HRV (e.g., RMSSD) in trained subjects (James et al. 2002; Kaikkonen et al. 2008; Seiler et al. 2007), while HR remains elevated for a long time into recovery (Seiler et al. 2007).

Changing match contexts can disrupt "normal" sleeping patterns of players (i.e., change of location, kick-off time, and travel (Fullagar et al. 2016)). In the current study, female athletes presented delayed sleep onset time (+ 36min) and increased sleep latency (+ 5min) following AM compared to HM. A possible explanation for these findings might be that players arrived home later after AM. Additionally, it could be speculated that post-match social activities (Nedelec et al. 2015) had a greater influence after AM than HM since players travelled back home together.

Long and international air travel could increase jet-lag symptoms and impair mood state (Bonnar et al. 2018), and subsequently affect sleep (Nedelec et al. 2015) and HRV (Egan-Shuttler et al. 2018) indices in trained athletes. However, these issues seem not to be solely related to travel distance *per se* (Carriço et al. 2017) as the players in the

current study did not have to travel by bus for more than 3 hours after AM.

One of the strengths of the current study, and a novelty in the investigation of sleep and cardiac autonomic activity in high level athletes, is that we used actigraph units and HR monitors simultaneously to analyze sleep and HRV in a real-world scenario. Practical implications are that, together, actigraphic variables and HRV indices provide more complete information on sleep patterns and cardiac autonomic function corresponding to athlete recovery. Moreover, both indices can be used to improve the quality of monitoring training and match loads, are easily assessed at the training/match facilities and at the athletes' own homes, and can be implemented in a team's daily routine.

This study has some limitations to be considered. Chronotype, core body temperature, hormones (e.g., menstrual cycle), level of light exposure during daytime, and food intake before bedtime were not assessed. Therefore, the mechanisms underlying sleep quantity changes observed after exercise can only be speculated. Moreover, this study was limited by the fact that players were not full-time athletes, and other circumstances of their daily lives (e.g., job, education) were not considered when comparing sleep and HRV at different times of day and match locations.

In conclusion, the results of this study suggest that time of day for soccer practice (i.e., training at night), and match location (i.e., away matches) may cause disruption in sleep patterns and/or autonomic cardiac activity in female soccer players. It is suggested that athletes and coaches organize the training program not only according to match schedules, but also aiming to improve sleep routines for optimal recovery.

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Disclosure Statement

No potential conflict of interest was reported by the authors.

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References

Akaike H. 1974. A new look at the statistical model identification. IEEE Trans Automat Contr. 19:716–23.

Al Haddad H, Laursen PB, Ahmaidi S, Buchheit M. 2009. Nocturnal heart rate variability following supramaximal intermittent exercise. Int J Sports Physiol Perform. 4:435–47.

Alsaadi SM, McAuley JH, Hush JM, Bartlett DJ, McKeough ZM, Grunstein RR, Dungan GC 2nd, Maher CG. 2014. Assessing sleep disturbance in low back pain: the validity of portable instruments. PLoS One. 9: e95824.

Bangsbo J. 1994. The physiology of soccer–with special reference to intense intermittent exercise. Acta Physiol Scand Suppl. 619:1–155.

Banister E. 1991. Modeling elite athletic performance. In: MacDougall JD, Wenger HA, Green HJ, editors. Physiological testing of the high-performance athlete. Champaign (IL): Human Kinetics; p. 403–24.

Bonato M, Agnello L, Galasso L, Montaruli A, Roveda E, Merati G, La Torre A, Vitale JA. 2017a. Acute modification of cardiac autonomic function of high-intensity interval training in collegiate male soccer players with different chronotype: a cross-over study. J Sports Sci Med. 16:286–94.

Bonato M, La Torre A, Saresella M, Marventano I, Merati G, Vitale JA. 2017b. Salivary cortisol concentration after high-intensity interval exercise: time of day and chronotype effect. Chronobiol Int. 34:698–707.

Bonnar D, Bartel K, Kakoschke N, Lang C. 2018. Sleep interventions designed to improve athletic performance and recovery: a systematic review of current approaches. Sports Med. 48:683–703.

Borsheim E, Bahr R. 2003. Effect of exercise intensity, duration and mode on post-exercise oxygen consumption. Sports Med. 33:1037–60.

Brandenberger G, Buchheit M, Ehrhart J, Simon C, Piquard F. 2005. Is slow wave sleep an appropriate recording condition for heart rate variability analysis? Auton Neurosci. 121:81–86.

Buchheit M, Simon C, Piquard F, Ehrhart J, Brandenberger G. 2004. Effects of increased training load on vagal-related indexes of heart rate variability: a novel sleep approach. Am J Physiol Heart Circ Physiol. 287:H2813–2818.

Cajochen C. 2007. Alerting effects of light. Sleep Med Rev. 11:453–64.

Camm AJ, Malik M, Bigger JT, Breithardt G, Cerutti S, Cohen RJ, Kleiger, R.E., Malliani, A., Moss, A.J, Schwartz, P.J, et al. 1996. Heart rate variability - standards of measurement, physiological interpretation, and clinical use. Circulation. 93:1043–65.

Carriço S, Skorski S, Duffield R, Mendes B, Calvete F, Meyer T. 2017. Post-match sleeping behavior based on match scheduling over a season in elite football players. Sci Med Football. 2:9–15.

Costa JA, Brito J, Nakamura FY, Oliveira EM, Rebelo AN. 2018. Effects of late-night training on "Slow-wave sleep episode" and hour-by-hour-derived nocturnal cardiac autonomic activity in female soccer players. Int J Sports Physiol Perform. 13:638–44.

Egan-Shuttler JD, Edmonds R, Ives SJ. 2018. The efficacy of heart rate variability in tracking travel and training stress in youth female rowers: a preliminary study. J Strength Cond Res. doi:10.1519/JSC.0000000000002499.

Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, Doleshal P, Dodge C. 2001. A new approach to monitoring exercise training. J Strength Cond Res. 15:109–15.

Fowler P, Duffield R, Vaile J. 2015. Effects of simulated domestic and international air travel on sleep, performance, and recovery for team sports. Scand J Med Sci Sports. 25:441–51.

Fullagar HH, Skorski S, Duffield R, Julian R, Bartlett J, Meyer T. 2016. Impaired sleep and recovery after night matches in elite football players. J Sports Sci. 34:1333–39.

Gupta L, Morgan K, Gilchrist S. 2017. Does elite sport degrade sleep quality? A systematic review. Sports Med. 47:1317–33.

Hooper SL, Mackinnon LT, Howard A, Gordon RD, Bachmann AW. 1995. Markers for monitoring overtraining and recovery. Med Sci Sports Exerc. 27:106–12.

Hopkins WG. 2009. Statistics in observational studies. In: Verhagen E, van Mechelen W, editors. Methodology in sports injury research. Oxford (UK): OUP; p. 69–81.

James DV, Barnes AJ, Lopes P, Wood DM. 2002. Heart rate variability: response following a single bout of interval training. Int J Sports Med. 23:247–51.

Juliff LE, Halson SLPeiffer JJ. 2015. Understanding sleep disturbance in athletes prior to important competitions. J Sci Med Sport. 18(1):13-18.

Kaikkonen P, Rusko H, Martinmaki K. 2008. Post-exercise heart rate variability of endurance athletes after different high-intensity exercise interventions. Scand J Med Sci Sports. 18:511–19.

Lastella M, Roach GD, Halson SL, Sargent C. 2015. Sleep/wake behaviours of elite athletes from individual and team sports. Eur J Sport Sci. 15:94–100.

Mallampalli MP, Carter CL. 2014. Exploring sex and gender differences in sleep health: a society for women's health research report. J Womens Health (Larchmt). 23:553–62.

Mourot L, Bouhaddi M, Perrey S, Cappelle S, Henriet MT, Wolf JP, Rouillon JD, Regnard J. 2004. Decrease in heart rate variability with overtraining: assessment by the Poincare plot analysis. Clin Physiol Funct Imaging. 24:10–18.

Nédélec M, Dawson B, Dupont G. 2018. Influence of night soccer matches on sleep in elite players. J Strength Cond Res. doi:10.1519/JSC.0000000000002906. Epub ahead of print.

Nedelec M, Halson S, Abaidia AE, Ahmaidi S, Dupont G. 2015. Stress, sleep and recovery in elite soccer: a critical review of the literature. Sports Med. 45:1387–400.

O'Connor PJ, Breus MJ, Youngstedt SD. 1998. Exercise-induced increase in core temperature does not disrupt a behavioral measure of sleep. Physiol Behav. 64:213–17.

Parak J, Korhonen I 2015. Accuracy of firstbeat body guard 2 beat-to-beat heart rate monitor. [accessed 2017 May 8]. https://www.firstbeat.com/app/uploads/2015/10/white_paper_bodyguard2_final.pdf.

Pollock ML, Gaesser GA, Butcher JD, Després JP, Dishman RK, Franklin BA, Garber, C.E. 1998. ACSM position stand: the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med Sci Sports Exerc. 30:975–91.

Sadeh A, Sharkey KM, Carskadon MA. 1994. Activity-based sleep-wake identification: an empirical test of methodological issues. Sleep. 17:201–07.

Sargent C, Halson S, Roach GD. 2014. Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. Eur J Sport Sci. 14 (Suppl 1):S310–315.

Seiler S, Haugen O, Kuffel E. 2007. Autonomic recovery after exercise in trained athletes: intensity and duration effects. Med Sci Sports Exerc. 39:1366–73.

Skein M, Duffield R, Minett GM, Snape A, Murphy A. 2013. The effect of overnight sleep deprivation after competitive rugby league matches on postmatch physiological and perceptual recovery. Int J Sports Physiol Perform. 8:556–64.

Staunton C, Gordon B, Custovic E, Stanger J, Kingsley M. 2017. Sleep patterns and match performance in elite Australian basketball athletes. J Sci Med Sport. 20:786–89.

TaskForce. 1996. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task force of the European society of cardiology and the North

American society of pacing and electrophysiology. Circulation. 93:1043–65.

Vitale JA, Banfi G, Galbiati A, Ferini-Strambi L, Torre A. 2018. Effect of night-game on actigraphy-based sleep quality and perceived recovery in top-level volleyball athletes. Int J Sports Physiol Perform. 1–14.

Vitale JA, Bonato M, Galasso L, La Torre A, Merati G, Montaruli A, Roveda E, Carandente F. 2017a. Sleep quality and high intensity interval training at two different times of day: a crossover study on the influence of the chronotype in male collegiate soccer players. Chronobiol Int. 34:260–68.

Vitale JA, Weydahl A. 2017b. Chronotype, physical activity, and sport performance: a systematic review. Sports Med. 47:1859–68.

Vuori I, Urponen H, Hasan J, Partinen M. 1988. Epidemiology of exercise effects on sleep. Acta Physiol Scand Suppl. 574:3–7.

Watson NF, Badr MS, Belenky G, Bliwise DL, Buxton OM, Buysse D, Dinges DF, Gangwisch J, Grandner MA, Kushida C, et al. 2015. Recommended amount of sleep for a healthy adult: a joint consensus statement of the American academy of sleep medicine and sleep research society. Sleep. 38:843–44.

Study 4

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RESEARCH ARTICLE

Intra-individual variability of sleep and nocturnal cardiac autonomic activity in elite female soccer players during an international tournament

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Abstract

Purpose

To describe individual sleeping patterns and nocturnal cardiac autonomic activity of National team female soccer players during an international tournament.

Materials and methods

Twenty elite female soccer players (aged 25.2±3.1 years) wore wrist actigraph units and heart rate (HR) monitors during night-sleep throughout 9 consecutive days (6 day-time training sessions [DT], 2 day-time matches [DM], and 1 evening-time match [EM]) of an international tournament. Training and match loads were monitored using the session-rating of perceived exertion (s-RPE) and wearable 18-Hz GPS (total distance covered [TD], training and match exposure time, and high-speed running [HSR]) to characterize training and match loads.

Results

Individually, s-RPE, TD, exposure time, and HSR during training sessions ranged from 20 to 680 arbitrary units (AU), 892 to 5176 m, 20 to 76 min, and 80 to 1140 m, respectively. During matches, s-RPE, TD, exposure time, and HSR ranged from 149 to 876 AU, 2236 to 11210 m, 20 to 98 min, and 629 to 3213 m, respectively. Individually, players slept less than recommended (<7 hours) on several days of the tournament, especially after EM (n = 8; TST ranging between 6:00–6:54 h). Total sleep time coefficient of variation (CV) ranged between 3.1 and 18.7%. However, all players presented good sleep quality (i.e., sleep efficiency ≥75%; individual range between: 75–98%) on each day of the tournament. Most of the players presented small fluctuations in nocturnal cardiac autonomic activity (individual nocturnal heart

would not have and all relevant data can be accessed in the same manner as the authors, from the Data Protection Office, Portuguese Football Federation Data Access.

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rate variability [HRV] ranged from 3.91–5.37 ms and HRV CV ranged from 2.8–9.0%), while two players presented higher HRV CV (11.5 and 11.7%; respectively).

Conclusion

Overall, this study highlights the substantial individual variability in sleep and HRV measures, suggesting the adoption of an individual approach to monitor sleep, training and match loads and recovery, to better understand how players cope with highly demanding competitions.

Introduction

Elite soccer players are constantly exposed to multiple high physiological demands due to an elevated number of training sessions and matches played in National and international competitions, often with congested match calendars [1]. In some women's competitive tournaments, only one to two days of recovery are given between matches [2]. In this scenario, optimizing recovery is required to reduce the risk of transitioning into a state of excessive fatigue as well as to reduce the risk of injury [3].

One of the most critical aspects of the recovery *continuum* for elite athletes is obtaining a sufficient quantity and quality of sleep [4]. In fact, athletes and coaches from several sports including soccer have ranked sleep as the most important recovery strategy [5]. A minimum of 7–9 hours of total sleep time (TST) per night is generally recommended to promote optimal health and cognitive function among adults aged 18 to 60 years old [6]. Although there is no general consensus regarding the amount of sleep an elite athlete should obtain to maintain optimal performance [7], athletes who obtain less than 7 hours of sleep per night might have an increased likelihood of injury [4, 8]. In fact, some studies have found sleep durations of less than 7 hours in elite athletes, especially in soccer teams. Sargent et al. [7], for example, found that athletes (from individual and team sports) obtained an average of 6.5 hours sleep per night, ranging from 5 to 8 hours. Lastella et al. [9] confirmed these results, finding that average sleep duration for elite athletes (including elite soccer players) was 6.8 hours, ranging from 5.5 hours to 8 hours. Based on these results, it seems that athletes are probably not getting sufficient sleep. Therefore, and importantly, athletes that might be sleeping for less than 7 hours [10, 11] may require an extension of sleep time. In fact, extended TST (commonly used as sleep quantity index [4]) can lead to better psychomotor accomplishment and technical accuracy [12], with likely positive effects on competitive performance [13]. Besides sleep quantity analyses, sleep efficiency (SE; i.e., time asleep as a percentage of time in bed) is recommended for monitoring sleep patterns as a sleep quality variable [4, 14], especially in elite athletes [15]. According to the National Sleep Foundation report [16], SE $\geq$85% is generally recommended as an appropriate indicator of good sleep quality, whereas a sleep efficiency $\leq$74% indicates inappropriate sleep quality for young adults/adults. As already mentioned, athletes are often unable to achieve $\geq$7 hours of TST and $\geq$85% SE during training and competition [4]. It is important to analyze the achievement of good sleep indices (quality and efficiency) at the group level and individual level, but possible interventions should primarily take into account the individual sleep behaviors and its implications to each athlete's performance.

Due to a variety of essential immunological and metabolic processes which occur during sleep, it seems that a conceptual relationship exists between the quantity and quality of sleep and the capacity of athletes to recover and perform [17]. However, the majority of research

available examining the sleep of athletes, especially in women, has typically averaged data across several nights, providing a mean estimate of usual sleep [7, 9, 18–20]. While such an approach is useful to provide basic insight into sleep in athletes, it lacks details of how sleep may vary across multiple nights [21]. Moreover, individual variability can reflect differences within individuals over time [22], with high intra-individual sleep variability indicating the need for individualized sleep education strategies and interventions to promote appropriate sleep [21]. Additionally, the coefficient of variation (CV) of sleep parameters (e.g. TST_{CV}), classified as a measure of intra-individual sleep variability [23], has been calculated to measure nocturnal sleep variability [24]. In this respect, it may be important to include the presentation of sleep data by encompassing individual responses, in addition to general group means [21]. In addition, special attention should be given to the sleep behavior of elite athletes (e.g., TST_{CV}) during international tournaments (a period of highly congested fixtures) since sleep deficits can impair performance [25].

Although sleep is considered a restorative behavior, only recently there has been growing interest for the assessment of the autonomic nervous system (ANS) activity through the use of heart rate (HR) variability (HRV) (considered an indirect marker of the cardiac ANS activity [26]) during overnight sleep in athletes. Since the cardiac ANS activity is highly sensitive to environmental conditions (e.g., noise, light, temperature [27]), it is important that precautions be taken to standardize recording conditions in order to isolate the training-induced effects [28] on the cardiac ANS activity. Therefore, night recordings represent theoretically the best (more standardized) recording condition for HR and HRV monitoring [29, 30]. Recently, there has also been growing interest in the use of HRV measurements during sleep to evaluate exercise-induced disturbances in allostatic load (i.e., adaptive processes that maintain homeostasis through the production of mediators such as adrenalin, cortisol, and other chemical messengers) [31], and recovery from daily training and other sources of stress [19, 20, 32]. In fact, it is currently accepted that overnight sleep measurements over consecutive days are appropriate for tracking the recovery of HRV following high-intensity exercise [33]. However, standardized training programs within team sport settings have often produced sparse adaptive results, with high responders and low responders often getting lost in averaged data reports [34]. As a consequence, an increased desire for training individualization in team sport settings has given rise to a variety of athlete-monitoring strategies, enabling coaches to better manage fatigue and manipulate training prescription on an individual basis [35].

Vagal indices of HRV, such as the logarithm of the root mean square of successive R-R interval differences (lnRMSSD), reflecting cardiac parasympathetic modulation, are sensitive to fatigue and have been useful in evaluating individual training adaptation in soccer players [36, 37]. Furthermore, the weekly (4–7 days) CV of lnRMSSD ($lnRMSSD_{CV}$) may provide valuable information concerning training-induced perturbations in homeostasis, i.e., can reflect the day-to-day variations in cardiac parasympathetic activity [36, 38, 39]. In general, athletes with a lower $lnRMSSD_{CV}$ are more aerobically fit and seem to cope better with training and match loads [28, 40, 41]. Thus, athletes with high TST and SE and lnRMSSD are expected to experience less perturbation in sleep patterns [23] and cardiac autonomic activity [42].

Although data exist on the role of sleep in recovery and on the impact of various interventions (e.g. competitions, time of day for training, training and match loads) on sleep quality/quantity, there is a need of more studies to describe individual sleep variability during international tournaments, especially in elite female athletes, since sleep disturbances (e.g. reduced sleep quantity) can affect performance outcomes [43]. These investigations may identify potential factors related to disturbed sleep and nocturnal HRV, which could assist in better defining and recommending appropriate sleep hygiene strategies and more adequately

managing fatigue, as well as manipulation of training prescription and post-match recovery on an individual basis. Therefore, the aim of this study was to describe sleeping patterns and nocturnal HRV individual profiles of elite female soccer players from a National team during an international tournament.

Materials & methods

Subjects

Twenty elite outfield female soccer players (age: 25.2±3.1 years; height: 167.2±4.8 cm; body mass: 57.8±3.8 kg; mean ± SD) competing in the Portuguese National team volunteered to participate in the study, during an international tournament (Algarve Cup 2018). The study design was carefully explained to the subjects, and written informed consent was obtained. The study followed the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of Sports, University of Porto (CEFADE 03.2017).

Study design

The study followed a descriptive, observational design, highlighting the individual sleep and overnight HRV responses of elite female soccer players during an international competition. Data collection was performed throughout 9 consecutive days (encompassing 6 day-time training sessions; DT [start ranged between 11:00AM–5:30 PM], 2 day-time matches; DM [both started at 3:00 PM], and 1 evening-time match; EM [started at 7:00 PM) of an international tournament (Table 1). Players' sleeping patterns and nocturnal cardiac autonomic activity were monitored every night throughout the tournament. Players wore wrist actigraph units and HR monitors during night-sleep. Training and match loads were quantified by session-rating of perceived exertion (s-RPE), total distance covered (TD), training and match exposure time (volume), and high-speed running (HSR) to characterize training practices and competition demands during the observation period.

Throughout the study (i.e., 9 consecutive days of the tournament), the subjects were hosted in the same hotel. The players slept in twin rooms with separate beds (allocated by the technical staff together with the players). All meals were eaten at the same hotel restaurant (i.e., breakfast [until 9:30 AM], lunch [at 12:45 PM] and dinner [at 8:00 PM]). It is important to highlight that time schedule for dinner on the EM day was changed (i.e. ~2 hours later [at 10:00 PM]) compared to the remaining days of the tournament. This was the only time schedule change during all tournament. Similarly, all training sessions were conducted within the hotel's sports complex. All training sessions and matches were performed on an outdoor natural grass pitch. Ambient temperature (i.e. outdoor) ranged from 16–18˚C during the day and

Table 1. Data collection during 9 consecutive days of an international tournament in elite female soccer players. Training load (TL) was assessed each day-training (DT), day-match (DM), and evening-match (EM). Cardiac autonomic activity and actigraphy were assessed during night-sleep, and after each training session and match (represented as grey area). Scheduled time and duration of training and matches are also illustrated.

Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
TL (RPE, GPS); Cardiac autonomic activiy; Actigraphy	TL (RPE, GPS); Cardiac autonomic activiy; Actigraphy	TL (RPE, GPS); Cardiac autonomic activiy; Actigraphy	TL (RPE, GPS); Cardiac autonomic activiy; Actigraphy	TL (RPE, GPS); Cardiac autonomic activiy; Actigraphy	TL (RPE, GPS); Cardiac autonomic activiy; Actigraphy	TL (RPE, GPS); Cardiac autonomic activiy; Actigraphy	TL (RPE, GPS); Cardiac autonomic activiy; Actigraphy	TL (RPE, GPS); Cardiac autonomic activiy; Actigraphy
DT1; 5:30 PM; (65 ± 2 min)	**DT2;** 11:30 AM; (70 ± 17 min)	**DM1;** 3:00 PM; (67 ± 26 min)	**DT3;** 4:30 PM; (34 ± 11 min)	**DM2;** 3:00 PM; (79 ± 23 min)	**DT4;** 4:00 PM; (71 ± 20 min)	**DT5;** 4:00 PM; (57 ± 2 min)	**EM3;** 7:00 PM; (63 ± 27 min)	**DT6;** 4:00 PM; (51 ± 10 min)

Abbreviations: RPE, rating of perceived exertion; GPS, global positioning system

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10–12˚C during the night. The competitive matches were held in 3 different stadiums located in the same district (Faro, Portugal; the furthest stadium from the hotel was ~1h by bus). Therefore, long journeys and the consequences (e.g., travel fatigue and jet leg) were avoided. Training schedules were set at the discretion of the team coaching staff. There was no interference by the research team in the athletes' regular training schedule or sleep/wake patterns. The athletes were free to consume snacks, nutritional supplements, and caffeine during the data collection period.

Measurements

Training and match load monitoring. Individual training and match exposure time was routinely recorded by a member of the team's medical staff. Subsequently, the recorded exposure time was used to select the actual global positioning system (GPS) training data. The same procedure was used during matches, based on the individual effective playing time, including substitute players. The amount of activities performed during the tournament was monitored using wearable 18-Hz GPS units (STATSports Apex, Northern Ireland). The accuracy of this device has been previously examined, reporting a nearly perfect criterion validity to measure distance during team sport specific movements (ICC = 0.98)[44]. A special vest was tightly fitted to each player, with the receiver placed between the scapulae. All devices were activated 15-min before the data collection to allow acquisition of satellite signals in accordance with the manufacturer's instructions. In addition, in order to avoid inter-unit error, each player wore the same GPS unit throughout the tournament [45]. Data were subsequently downloaded and adjusted to training and match exposure using corporate software (STATSports Apex, Northern Ireland). TD covered was adopted as the measure of training and match volume. High-speed running (HSR, >12.6 km·h^{-1}) was adopted as the measure of high-intensity activity performed, according to a recent study in top-level female players [46].

Psychophysiological response to exercise was quantified using the session-rating of perceived exertion method (s-RPE). Throughout the tournament, the players reported individual RPE using the Borg category ratio scale (CR10) via a customized mobile application, approximately 30 min after each training session or match. The CR10 score (perceived intensity) was subsequently multiplied by individual exposure time (training and match volume), thus providing an overall load quantification of the session or match [47].

Sleep monitoring. Night-sleep was assessed using 3-axial accelerometers (Actigraph LLC wGT3X-BT, Pensacola, USA) worn on the non-dominant wrist. Wrist-worn accelerometers have been used to monitor sleep in elite athletes [15], and validated against polysomnography (PSG; [48]). Data were analysed using corporate software (ActiLife LLC Pro software v6.13.3, Pensacola, USA). The sampling frequency was 50 Hz and the epoch of activity counts was 60 s [49]. All sleep variables were determined every night throughout the tournament using the Sadeh's algorithm [49]. Objective sleep measures included total sleep time (total amount of sleep obtained), time in bed (time between lying down until getting up the next day), wake-up time (time between the last minute of sleep and getting up from bed), sleep onset time (time of the first epoch of sleep between time of trying to initiate sleep and time at wake up), wake after sleep onset (number of min awake after sleep onset), sleep fragmentation index (sum of mobility and immobility accesses in one minute, divided by the number of immobility accesses), latency (time in minutes attempting to fall asleep), and sleep efficiency (percentage of time in bed that was spent asleep) [49]. It is important to mention that although some studies have reported SE $\leq$85% as insufficient sleep quality [4], according to the latest National Sleep Foundation report [16], SE ranging from 75–84% is considered uncertain for young adults/adults, whereas SE $\leq$74% indicates inappropriate sleep quality for the respective age category.

Therefore, sleep quantity (TST) and sleep quality (SE) were analysed according to the Sleep National Foundation report (i.e., TST <7h; 420 min as an indicator of inappropriate sleep quantity, and SE ≤74% as inappropriate sleep quality) [16].

Cardiac autonomic activity monitoring. The slow-wave sleep episode (SWSE) method, which accounts for the deep stage of sleep [36], was used to analyse the cardiac autonomic activity during night-sleep [29]. This method records 10 minutes of normal RR intervals, considering the criteria proposed by Brandenberger et al., (2005). HR monitors (Firstbeat Bodyguard2®, Firstbeat Technologies, Finland) were used during sleep. This device has been validated against standard electrocardiogram equipment to detect heartbeats [50]. The RR intervals analyzed in time domain measures included mean RR interval (mRR), mean HR, RMSSD (square root of the mean of the sum of the squares of differences between adjacent normal RR intervals; vagal modulation index), and SDNN (standard deviation of all NN [RRintervals] interval). RR intervals were also used to produce the Poincaré plot SD_1 (short-term beat-to-beat variability) and SD_2 (long-term beat-to-beat variability) values. Fast Fourier Transform (Welch's periodogram: 300-s window with 50% overlap)[51] was used to obtain measures of nocturnal cardiac autonomic activity in the frequency domain, considering both LF (0.004–0.15 Hz) and HF (0.15–0.4 Hz) indices. The ratio (i.e., LF/HF) index was calculated from the non-transformed LF and HF data [51]. In addition, to reduce any potential non-uniformity or skewness in HRV, data were log-transformed by taking the natural logarithm (ln) before conducting any statistical analyses [52]. In all cases, the RR recordings were exported to the Kubios version 3.2 Heart Rate Variability software (Biosignal Analysis and Medical Imaging Group at the Department of Applied Physics, University of Kuopio, Kuopio, Finland).

Buchheit [36] proposed 3% as the fixed smallest worthwhile change (SWC) to detect eventual changes related to positive and negative adaptations in HRV-derived indices. Given that both 0.5×CV [36] and 1×CV have been acceptably used to account for within-athlete variations in HRV-derived indices, it is possible to state that using 3% as proposed by Buchheit [36] is acceptable and conservative for lnRMSSD, especially for soccer players [42].

Statistical analysis. Sample distribution was tested using the Shapiro–Wilk test for sleep patterns, nocturnal cardiac autonomic activity indices (HRV), and training and match load variables for each day of the tournament. Sleep patterns, nocturnal autonomic activity, and training load variables displayed during the 9 days of the tournament are presented as mean ± SD for the indices that displayed normal distribution and presented as median (interquartile range) for data that did not present normal distribution. The coefficient of variation (CV; CV = ([SD/mean] ×100) was calculated for the whole group and also intra-individually for TST and lnRMSSD indices across 9 days of the international tournament. The SWC was calculated from the intra-individual CV of lnRMSSD ($lnRMSSD_{CV}$), considering the 9 days of the tournament [36].

A within-subjects linear mixed model analysis was performed to examine differences in TST, SE, and nocturnal lnRMSSD variables across 9 days of the tournament. An α-level of 0.05 was set as the level of significance for statistical comparisons. The days of the tournament (i.e., DT, DM, and EM) were included as a fixed effect and player identity (subject ID) as the random effect. Furthermore, among the recommended variance-covariance structure models, compound symmetry was selected according to the smallest Akaike Information Criterion assessment [53], based on the Restricted Maximum Likelihood method. Pairwise comparisons (Bonferroni) were used to show the day-to-day mean differences for TST, SE, and nocturnal lnRMSSD indices.

Within-subjects correlations were calculated between sleep indices (TST and SE), HRV (lnRMSSD) and load parameters (TD, HSR, s-RPE and exposure time) [54]. In repeated-measures studies, it is important to quantify within-subject correlations by modelling the

longitudinal dataset as a whole and reducing the variation between subjects. For instance, rather than pooling all the data, or calculating correlations separately for individual participants, this approach quantifies the correlation and associated 95% confidence intervals (95% CI) between a covariate and outcome, while taking into account the within-participant nature of the study design, based on the correct degrees of freedom. The magnitudes of correlation were qualitatively interpreted using the following criteria: trivial ($r \leq 0.1$), small (r = 0.1–0.3), moderate (r = 0.3–0.5), large (r = 0.5–0.7), very large (r = 0.7–0.9) and almost perfect ($r \geq 0.9$) [55]. When 95% CI overlapped positive and negative values, the effect was deemed to be unclear.

Results

Missing data

Technical problems and/or player compliance resulted in some missing data points (sleep variables: valid cases, n = 142 [92%], and missing cases, n = 13 [8%]; nocturnal HRV indices: valid cases, n = 137 [88%], and missing cases, n = 18 [12%]; TD, exposure time and HSR: valid cases, n = 137 [88%], and missing cases, n = 18 [12%]; s-RPE: valid cases, n = 103 [67%], and missing cases, n = 52 [34%]).

Training and match load variables

As a group, the s-RPE, TD, exposure time, and HSR during training sessions ranged from 131 to 360 arbitrary units (AU), 2201 to 4284 m, 34 to 76 min, and 130 to 756 m, respectively. During matches these variables ranged from 504 to 602 AU, 7012 to 7746 m, 64 to 83 min, and 1678 to 1888 m, respectively. These data are summarized in Fig 1 (Fig 1A, 1B, 1C and 1D).

Individually, the s-RPE, TD, exposure time, and HSR during training sessions ranged from 20 to 680 AU, 892 to 5176 m, 20 to 76 min, and 80 to 1140 m, respectively. During matches these values ranged from 149 to 876 AU, 2236 to 11210 m, 20 to 98 min, and 629 to 3213 m, respectively. These data are summarized in Fig 1 (Fig 1A, 1B, 1C and 1D).

Sleep variables

As a group, player TST ranged between 7:41±0:48 and 8:26±0:41 hours during all DT and both DM of the tournament, Table 2. However, a lower duration of TST was observed after EM (6:47±0:58 hours) compared to all days of the tournament ($p<0.001$), especially when compared to both DM_1 and DM_2 (-1:39±0:17 hours and -1:28±0:12 hours, respectively; $p<0.001$). In addition, a lower SE was found after EM compared to all days of the tournament ($p<0.001$), especially when compared to both DM_1 and DM_2 (-6±3% and -4±2%, respectively; $p<0.001$). All the sleep-related variables are presented in Table 2.

Individually, some players slept less than recommended (<7 hours; 420 min) after DT_1 (n = 4; player 8,13,19 and 20), DT_2 (n = 3; player 6, 13 and 20), DM_1 n = 0, DT_3 (n = 1; player 12), DM_2 (n = 6; 8, 10, 16 and 20), DT_4 (n = 2; player 12 and 13), DT_5 (n = 2; player 2 and 12), EM_3 (n = 8; player 5, 6, 8, 10, 12, 16, 17 and 20), and DT_6 (n = 1; player 20); especially after EM (TST range between 6:00–6:54 h). TST_{CV} ranged between 3.1 and 18.7% (Fig 2). Overall, all players presented good sleep quality (i.e., sleep efficiency ≥75%; individual range between 75–98%) across all days of the tournament (Fig 2).

Cardiac autonomic activity variables

As a group, nocturnal autonomic cardiac activity was not affected during the 9 days of the tournament. Overnight lnRMSSD ranged from 4.19±0.88 to 4.54±0.42 ln[ms] ($p>0.05$). Nocturnal autonomic cardiac activity data are presented in Table 3.

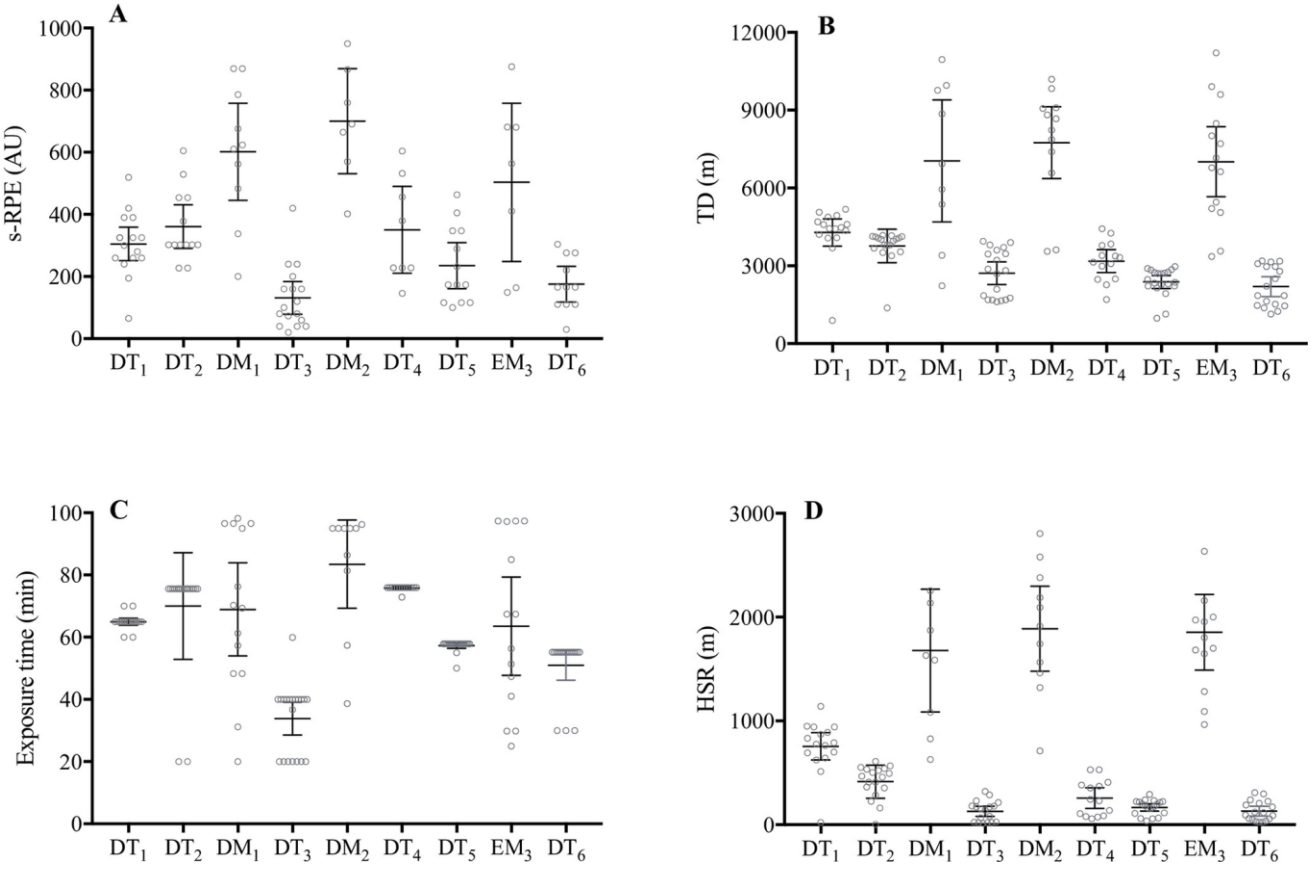


Fig 1. Individual subject session of perceived exertion (A), total distance (B), exposure time (C), and high-speed running (D) responses during 9 consecutive days of an international tournament in elite female soccer players. Group mean ± 95% confidence interval are presented (black lines) for s-RPE and HSR, and median (interquartile range) for TD and exposure time (black lines) for each day in elite female soccer players. Abbreviations: s-RPE, session-rating of perceived exertion; TD, total distance; HSR, high-speed running; DT, day-training; DM, day-match; EM, evening-match. Note: s-RPE: DT_1 (n = 15); DT_2 (n = 14); DM_1 (n = 10); DT_3 (n = 17); DM_2 (n = 7); DT_4 (n = 8); DT_5 (n = 13); EM_3 (n = 7); and DT_6 (n = 11). TD, exposure time, and HSR: DT_1 (n = 16); DT_2 (n = 18); DM_1 (n = 9); DT_3 (n = 18); DM_2 (n = 11); DT_4 (n = 14); DT_5 (n = 20); EM_3 (n = 13); and DT_6 (n = 18).

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Individually, two players (players 6 and 7) appeared to present higher $lnRMSSD_{CV}$ (11.7 and 11.5%; respectively), which occurred simultaneously with a reduced lnRMSSD average (3.66 and 2.73 ms; respectively), throughout the tournament, in contrast to the remaining team (individual lnRMSSD ranging between 3.91 and 5.37 ms, and $lnRMSSD_{CV}$ ranging between 2.8 and 9%) (Fig 3).

The within-subject correlation between sleep indices and nocturnal HRV with training and match load are presented in Table 4. All load parameters showed unclear correlations with TST, SE and lnRMSSD. Additionally, sleep and HRV (i.e. TST and SE with lnRMSSD) showed also unclear correlations (r = -0.035 [-0.47;0.41] and r = -0.07 [-0.49; 0.39], $P>0.05$, respectively).

Discussion

The main finding from the sleep results was that some players presented less TST than recommended during different days of the tournament (i.e., independently of being DT, DM and EM). However, after EM, a higher number of athletes slept for less than 7 hours in contrast to the remaining days of the tournament during which they presented adequate sleep duration. Nevertheless, all players displayed good sleep quality.

Table 2. Actigraphy sleep responses during 9 days comprising an international tournament in elite female soccer players. Values are mean ± standard deviation (SD) and median (interquartile range).

	DT_1 (n = 20)	DT_2 (n = 20)	DM_1 (n = 13) missing (n = 1; 7%)	DT_3 (n = 19) missing (n = 1; 5%)	DM_2 (n = 13) missing (n = 1; 7%)	DT_4 (n = 12) missing (n = 2; 14%)	DT_5 (n = 17) missing (n = 3; 15%)	EM_3 (n = 13) missing (n = 2; 13%)	DT_6 (n = 15) missing (n = 3; 16%)
Sleep onset time (h: min)	23:31±0:23*	23:12 ± 0:36*	23:14 ± 0:34*	23:26 ± 0:34*	23:19 ± 0:56*	23:48 ± 0:39*	23:30 ± 0:33*	0:45 ± 0:32	23:35 ± 0:39*
Wake up time (h: min)	8:27 ± 0:31	8:39 (0:36)	9:02 (1:01)	8:38 (0:37)	8:25 ± 0:22	8:14 ± 0:27	8:37 ± 0:27	8:56 ± 0:34	8:39 (0:43)
TIB (h: min)	9:06 ± 0:45	9:15 (0:58)	9:42 ± 0:28	9:03 ± 0:32	9:08 ± 1:11	8:21 ± 0:44	8:54 ± 0:56	7:50 ± 0:46	8:34 ± 0:33
TST (h: min)	7:56 ± 0:47*	7:58 ± 0:54*	8:26 ± 0:41*	7:54 ± 0:36*	8:15 ± 1:08*	7:41 ± 0:48*	8:02 ± 0:57*	6:47 ± 0:58	7:55 ± 0:38*
WASO (min)	44 (32)	59 (38)	61 ± 32	45 (37)	41 (35)	42 ± 25	53 ± 33	65 ± 35	63 (74)
SFI (%)	26 ± 9	26 ± 9	26 ± 8	29 ± 11	27± 10	23 ± 10	27 ± 9	32 ± 10	24 (18)
SE (%)	91 ± 6*	91 ± 6*	87 ± 4*	91 ± 6*	85 ± 5*	90 ± 6*	92 ± 6*	81 ± 7	91 ± 4*
Sleep latency (min)	4 ± 3	3 (2)	7 ± 2*	3 (2)	9 ± 4*	4 ± 3	3 (2)	20 ± 9	4 ± 3

*Significantly different compared to EM ($P<0.001$)

Abbreviations: DT, day-training; DM, day-match; EM, evening-match; TIB, time in bed; TST, total sleep time; WASO, wake after sleep onset; SFI, sleep fragmentation index; SE, sleep efficiency.

Note: The mean values represent only the players that trained and played on the respective day of the tournament (goalkeepers were excluded).

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The main finding from overnight HRV results was that most players seemed to present small fluctuations in nocturnal cardiac autonomic activity, while two players appeared to present higher $lnRMSSD_{CV,}$ occurring simultaneously with a reduced lnRMSSD average during the tournament, compared to the remaining players of the team.

Overall, as a group, players accumulated adequate sleep quantity and presented good sleep quality on all training days and DM of the tournament. However, significantly decreased durations of TST and SE were observed after EM compared to DM of the tournament. These results are in accordance with recent studies showing that soccer players presented sleep duration within the appropriate healthy range on training days and match days concluded before 6 PM, but slept significantly less, delayed bedtime, and presented a lower SE after matches starting after 6 PM [56, 57]. In fact, the impact of night matches (i.e., schedule time) on subsequent sleep is well established [58, 59]. For example, Sargent and Roach (2016) examined the sleep of elite Australian football players on the night immediately following a day match or following an evening match. During the night immediately after the evening match, the players initiated sleep 2.5 hours later and obtained 2.1 hours less sleep when compared to sleep immediately following the day match. In the present study, following EM, female soccer players initiated sleep much later compared to DM_1 and DM_2, and obtained less sleep quantity compared to DM_1 and DM_2. Another interesting result was that higher sleep latency was found after EM compared to DM_1 and DM_2. These results are in accordance with a large epidemiological survey that reported that 24% of respondents perceived difficulty in initiating sleep after late-evening exercise compared to 7% after early evening exercise [60]. Our results also agrees with recent ones showing that sleep latency in high-level female soccer players was negatively affected after night-training sessions (start 9:00 PM) compared to resting days and match days (3:00 PM)

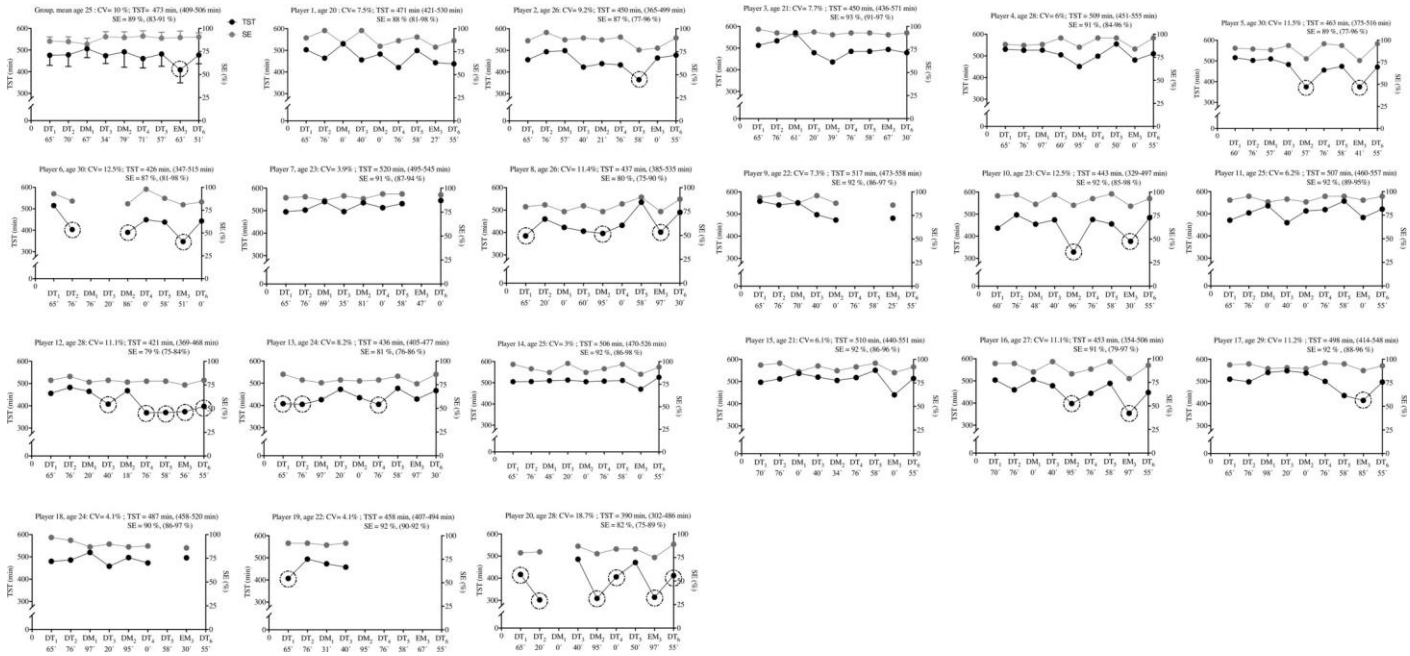


Fig 2. Group and individual subject (n = 20) total sleep time (TST) and sleep efficiency (SE) displayed during 9 days of an international tournament. Group and individual black and grey dots represent daily changes in TST and SE, respectively. TST and SE averages (with max-min values) are also presented. The black dashed circumferences represent the days that TST was lower than recommended (i.e., <420 min; <7 hours). The exposure time (min) for each day is also presented on all days of the tournament (x axis). Abbreviations: DT, day-training; DM, day-match; EM, evening-match; CV, coefficient of variation.

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[18], and suggest that late-evening exercise, occurring close to bedtime sleep, can impose a high risk of obstructing falling asleep at night. Thus, an acceptable explanation for the results observed in the present study could be the time scheduling of the matches, suggesting for the practitioners to implement sleep education strategies (e.g. sleep extension and/or naps) and interventions to promote appropriate sleep and recovery, especially after night competitions, since athletes are often unable to achieve recommended TST and SE, with lower values on the night of competition compared with the previous night [4].

A main finding from the individual sleep analysis was that some players slept less than recommended during the tournament, especially after EM. Importantly, seven out of eight players who played the EM also presented shorter TST on the night after EM (start 7 PM) compared with the previous night (DT). As already mentioned, these results are in accordance with a recent study [4] in elite athletes that showed nocturnal TST was shorter on the night after the match (start $\geq$6 PM) compared with the previous night (training and match or rest day).

Besides the training schedule, another possible explanation for the sleep results could be the training and match loads that players were exposed to during the tournament, especially during matches [4]. In fact, on days DM_2 and EM, more players that participated during the match slept less than recommended, with both days presenting the highest values of external load (e.g., HSR) and exposure time during the tournament. Interestingly, no sleep disturbances were found for any players that played DM_1. Nonetheless, despite the external training and match loads that players were exposed to, each player seemed to present good sleep quality across all days of the tournament. In fact, training and match load parameters were not significantly correlated with sleep, indicating that the amount of load parameters was not high enough to cause meaningful disturbances on the sleep indices, in this specific National female soccer team. These results could also be supported by the appropriate values of sleep latency

Table 3. Overnight cardiac autonomic activity (SWSE method) responses during 9 days of the international tournament in elite female soccer players. Values are mean ± standard deviation (SD) and median (interquartile range).

	DT_1 (n = 19) missing (n = 1; 5%)	DT_2 (n = 18) missing (n = 2; 10%)	DM_1 (n = 13) missing (n = 1; 7%)	DT_3 (n = 19) missing (n = 1; 5%)	DM_2 (n = 12) missing (n = 2; 14%)	DT_4 (n = 12) missing (n = 2; 14%)	DT_5 (n = 16) missing (n = 4; 20%)	EM_3 (n = 12) missing (n = 3; 20%)	DT_6 (n = 15) missing (n = 3; 17%)
Heart rate (bpm)	46.5 ± 5.2	47.4 ± 7.0	46.1 ± 7.3	46.9 ± 6.9	48.3 ± 4.7	46.0 ± 6.5	46.9 ± 6.0	48.8 ± 5.6	47.5 ± 7.1
RR interval (ln [ms])	7.2 ± 0.1	7.2 ± 0.2	7.2 ± 0.2	7.2 ± 0.1	7.1 ± 0.1	7.2 ± 0.1	7.2 ± 0.1	7.1 ± 0.1	7.2 ± 0.2
RMSSD (ln[ms])	4.4 ± 0.7	4.2 ± 0.9	4.4 ± 0.7	4.3 ± 0.7	4.4 ± 0.6	4.5 ± 0.4	4.3 ± 0.5	4.4 ± 0.7	4.5 ± 0.4
SDNN (ln [ms])	4.0 ± 0.7	3.9 ± 0.8	4.0 ± 0.6	3.9 ± 0.7	4.1 ± 0.6	4.2 ± 0.3	4.0 ± 0.4	4.1 ± 0.6	4.2 ± 0.3
SD1 (ln [ms])	4.0 ± 0.7	3.8 ± 0.9	4.0 ± 0.7	4.0 ± 0.7	4.1 ± 0.6	4.2 ± 0.4	4.0 ± 0.5	4.1 ± 0.7	4.2 ± 0.4
SD2 (ln [ms])	3.9 ± 0.6	3.8 ± 0.7	4.0 ± 0.5	3.9 ± 0.9	4.0 ± 0.5	4.1 ± 0.3	3.9 ± 0.3	4.0 ± 0.5	4.1 ± 0.3
LF (ln [ms^2])	6.5 ± 1.2	6.3 ± 1.4	6.9 ± 1.1	6.5 ± 1.5	6.8 ± 0.9	7.0 ± 0.6	6.4 ± 0.6	6.9 ± 1.0	6.9 ± 0.7
HF (ln [ms^2])	7.4 ± 1.4	7.1 ± 1.7	7.6 ± 1.5	7.3 ± 1.5	7.5 ± 1.2	7.7 ± 0.8	7.3 ± 0.9	7.5 ± 1.4	7.7 ± 0.8
LF/HF	0.7 (0.5)	0.6 (0.5)	0.8 (0.5)	0.6 (0.5)	0.6 ± 0.4	0.6 (0.5)	0.5 (0.4)	0.7 ± 0.5	0.4 (0.2)

Abbreviations: DT, day-training; DM, day-match; EM, evening-match; RR interval, variations between consecutive heart beats (beat to beat); RMSSD, square root of the mean of the sum of the squares of differences between adjacent NN intervals; SDNN, standard deviation of all NN interval; SD1, short-term beat-to beat variability; SD2, long-term beat-to-beat variability; LF, low frequency; HF, high frequency; LF/HF, ratio of the low-to high frequency power.

Note: The mean values represent only the players that trained and played on the respective day of the tournament (goalkeepers were excluded).

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observed for all players during the tournament. Additionally, in the current study, the within-player variability in TST (CV = 7.4%) was relatively low compared with a recent study that found a good within-player consistency of sleep (CV = 15.2%), across 8 days of rest (without exercise) and 8 days of night-training sessions in highly trained female soccer players [19]. Thus, even under stress imposed by tournament scheduling and training and match loads, the players maintained relatively good consistency in sleep habits to recover from the training sessions and matches.

Notably, six players seemed to have constantly "compensated" the low TST after participating in matches (independently of being DM or EM), including one player that played all matches (player 10), by extending sleep duration on the next day, probably as a "self-sleep hygiene" strategy. These findings are relatively consistent with previous data suggesting that training and competition schedules dictate the sleep/wake behavior of elite athletes [7, 9, 61]. Taken together, these findings are of considerable importance for athletes and coaches because nights of reduced sleep (i.e., 5–7 h of sleep per night) can lead to deficits in neurobehavioural performance and increases in subjective feelings of sleepiness and fatigue [62]. Therefore, if the training or competition schedule provides sufficient space for recovery strategies, extending bedtime to achieve prolonged sleep duration appears to be a beneficial approach. As prevalence of sleep restriction among athletes seems to be high [63], athletes are encouraged to implement 30 to 60 minutes of additional sleep each night as a 'self-experiment' which should be monitored and supported by staff members [64]. In addition, when feasible, athletes may also achieve additional sleep time by implementing daytime naps. Furthermore, habitual napping can be generally encouraged, whereas timing (i.e., preferably in the early afternoon) and

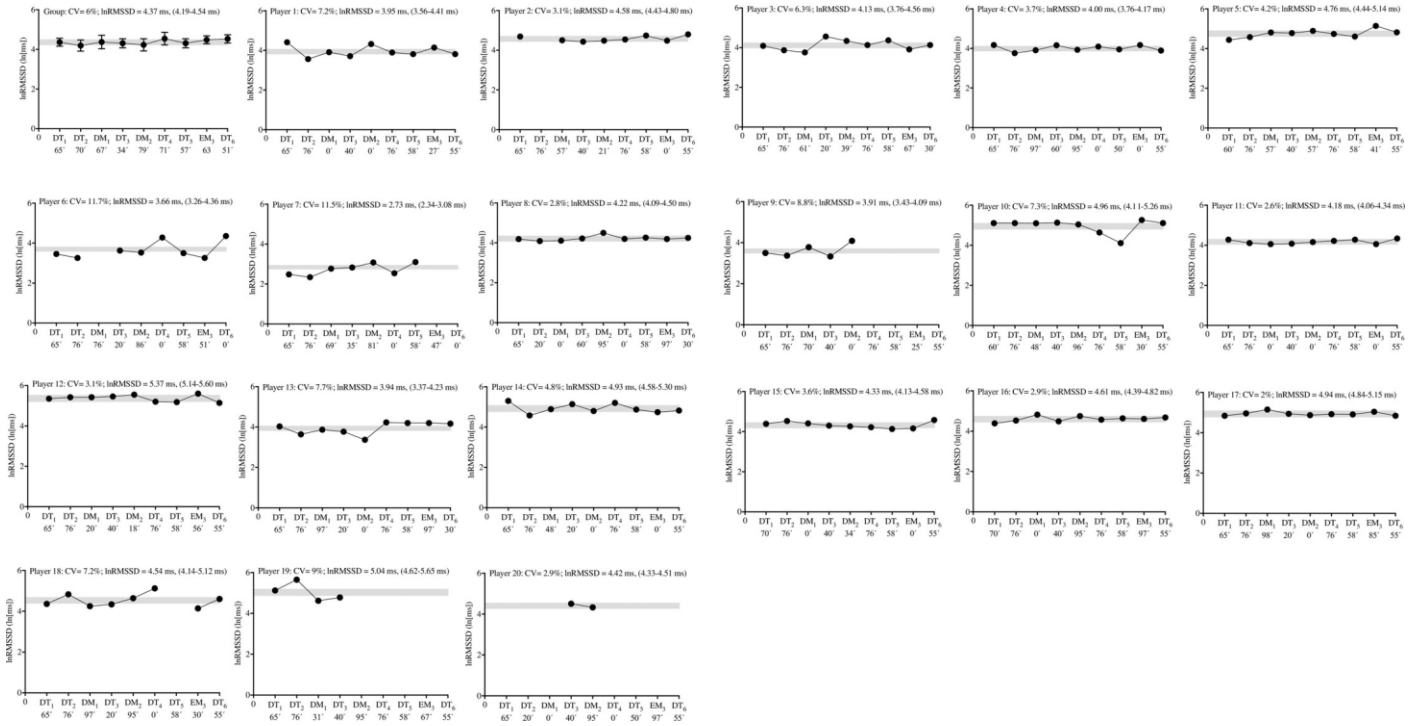


Fig 3. Group and individual subject (n = 20) cardiac parasympathetic activity displayed during 9 days of an international tournament. Group and individual black dots represent daily changes in natural logarithm of the root mean square of successive RR intervals (lnRMSSD). lnRMSSD averages (with max-min values) are also presented. The grey area represents the smallest worthwhile change zone (3%) [36]. The exposure time (min) for each day is also presented on all days of the tournament (x axis). Abbreviations: DT, day-training; DM, day-match; EM, evening-match; CV, coefficient of variation.

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duration (i.e., < 30 min) should be appropriately planned [65]. However, naps shorter than one hour are recommended, and not too close to bedtime as it may interfere with sleep [65].

In the current study, no significant changes in HRV were noticed across 9 days of an international tournament (independently of being DT, DM, or EM). Regarding the training and match loads of the investigated soccer team, it appears that the s-RPE of training sessions and matches during the international tournament were not high enough to cause overnight changes in the cardiac autonomic system in this specific National team. Our study showed that, as a group, elite female soccer players are able to tolerate up to ≈3000 AU across 9 days

Table 4. Within-subject correlation between sleep indices and nocturnal HRV with training and match load responses during an international tournament (n = 20).

		TD			HSR			s-RPE			Exposure time	
	P	r (95% CIs)	Description	*P*	r (95% CIs)	Description	*P*	r (95% CIs)	Description	*P*	r (95% CIs)	Description
TST	1.000	-0.27 (-0.64; 0.19)	Unclear	1.000	-0.21 (-0.60; 0.26)	Unclear	1.000	-0.25 (-0.62; 0.21)	Unclear	1.000	-0.21 (-0.60; 0.26)	Unclear
SE	0.393	0.19 (-0.28; 0.58)	Unclear	0.296	0.23 (-0.24; 0.61)	Unclear	0.348	0.21 (-0.26; 0.60)	Unclear	0.296	0.23 (-0.24; 0.61)	Unclear
lnRMSSD	0.424	0.18 (-0.29; 0.58)	Unclear	0.398	0.19 (-0.28; 0.58)	Unclear	0.407	0.19 (-0.28; 0.58)	Unclear	0.398	0.19 (-0.28; 0.58)	Unclear

Abbreviations: TST, total sleep time; SE, sleep efficiency; lnRMSSD, natural logarithm of square root of the mean of the sum of the squares of differences between adjacent NN intervals; CIs, confidence intervals; TD, total distance; HSR, high-speed running; s-RPE, session-rating of perceived exertion.

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or ≈600 AU per day of s-RPE during an international tournament, without presenting signs of severe nocturnal cardiac autonomic perturbation. In addition, training and match load parameters were not significantly correlated with HRV, indicating the absence of a dose-response feature that could suggest decreased tolerance to the higher loads experienced during the period of observation, in this sample of elite players. Accordingly, Costa et al., 2018 [20] found in highly trained female soccer players during a 7-day period of the competitive season that late-night soccer training did not affect nocturnal HRV indices in comparison with rest days. The authors suggest that the late-night training loads, as measured by training impulse (range between: 77.5 [36.5] and 110.8 [31.6] AU) and s-RPE (range between: 281.8 [117.9] and 369.0 [111.7] AU), were not high enough to disturb the cardiac autonomic function during sleep hours. Although National team players might be more resilient to sustained high levels of training and match load without presenting signs of severe nocturnal cardiac autonomic perturbation, this needs to be further investigated.

The $lnRMSSD_{CV}$ has also been assessed in studies involving highly-trained athletes as a marker of weekly variation in daily assessed lnRMSSD [66]. In a recent study [67], the authors suggested that a high diurnal $lnRMSSD_{CV}$ (subject 3 CV = 12.8% and subject 8 CV = 11.9%) was positively associated with perceived fatigue and negatively associated with the physical fitness of female soccer players. Moreover, another study found that diurnal $lnRMSSD_{CV}$ measured in swimmers can increase to values>10% during overload periods [68]. In our study, as a group, lnRMSSD derived from the SWSE method displayed low average CV (6%). In fact, most of the lnRMSSD values across all days of the tournament were located within the SWC range (3%) [36]. However, individually, two players (players 6 and 7) appeared to present higher $lnRMSSD_{CV,}$ which occurred simultaneously with a reduced average lnRMSSD during the tournament, contrasting with the remaining players of the team. Thus, overnight HRV during the international tournament was more sensitive to variation in these two players. Furthermore, it could be speculated that higher $lnRMSSD_{CV}$ associated with reduced average lnRMSSD during training and matches may be interpreted as a sign of overload [67]. Thus, although no significant correlation between lnRMSSD and training/match loads could be detected in the current study, it is highly advisable that coaches closely examine individual cases in which players can be suffering some detrimental effects during the competition in order to promote their recovery by means of sleep hygiene and other means [64].

With the purpose of monitoring athletes, measurements performed during consecutive days throughout the week are very useful to interpret adaptations [69]. In our study, players seemed to display lower perturbation of nocturnal cardiac autonomic activity, as expressed by the $lnRMSSD_{CV}$ [69]. Although the study comprised only 9 days of observation, it can be globally inferred that players were coping well with the training sessions and matches. In fact, a reduced $lnRMSSD_{CV}$ without a clear decrease in the lnRMSSD, which occurred for most of these female soccer players, may reflect the possibility of a high level of readiness to perform [66] during the international tournament. This finding corroborates previous studies assessing HRV during the day, in athletes who were awake [42, 68]. Finally, coaches and technical staff should give great attention to player 6 who presented the highest CV for both TST and lnRMSSD (12.5% and 11.7%, respectively) during the 9 days of the international tournament.

Limitations

Some limitations of the current study should be noted. Given that this study was conducted in a field setting (i.e., real-world scenario), there were many uncontrolled factors that may have affected the athletes' sleep, other than match/training scheduling and load (e.g. use of caffeine; social media after lights out, electronic devices, level of light exposure during daytime, use of

twin rooms, lack of standardization of room temperature, menstrual cycle phase of the players and perceived stress/well-being). In fact, additional measures (e.g., well-being ratings) are needed to contextualize and better interpret changes in HRV [67, 70]. Unfortunately, due to time and technical constraints, well-being, fitness level, and other types of perceived stress were not determined, and we recognize this as an important limitation of the current study to better understand the HRV values of each player during the tournament. Moreover, it is important to note that the fixed value of 3% was used as the SWC [36], but it was originally calculated from awake time measures, in general early in the morning. In the absence of overnight-specific SWC values, we have opted to use the 3% to identify lnRMSSD meaningful changes in athletes.

Eventual strategies that athletes used to increase their sleep duration during the day (e.g., naps) were not recorded. Nonetheless, the findings from the present study indicate that, if given the opportunity, elite female soccer players will try to compensate sleep loss due to evening match by extending their sleep in the following day to ameliorate fatigue and tiredness [11].

In addition, caution should be applied when interpreting the CV values for sleep and HRV, since on some days there were missing data. Furthermore, this study was limited by the fact that a "real baseline" was not evaluated for possible sleep and nocturnal HRV comparisons across the 9 days of the tournament.

Finally, while the s-RPE method may be simple, valid, and reliable, in this study we did not use other types of internal training and match load monitoring (e.g. HR monitors), which could provide objective information for the interpretation of the physiological responses of the players.

Conclusions

The present observational study is the first to systematically analyse consistent individual sleep and nocturnal HRV responses in elite female soccer players during a congested match schedule. Individually, some players presented less TST than recommended after some days of the tournament. However, the highest number of athletes sleeping less than 7 hours was found after EM compared with the remaining days of the tournament. Nevertheless, all players displayed good sleep quality for each day of the tournament. Additionally, most players seemed to present small fluctuations in nocturnal cardiac autonomic activity. Overall, this study highlights the substantial individual variability in sleep and HRV measures, suggesting the adoption of an individual approach to monitor sleep, training and match loads and recovery, to better understand how players cope with highly demanding competitions.

Practical applications

Our observational analysis of sleep and nocturnal HRV responses of elite female soccer players could assist coaches and practitioners to identify sleep and HRV disturbances during official competitions, especially during periods of highly congested fixtures, as occurs during international tournaments. In fact, identifying the optimal amount of sleep on an individual basis may be difficult [71], but at a minimum, adult and youth athletes who demonstrate an average sleep of less than 7 or 8 h, respectively, likely warrant additional evaluation to identify their specific sleep barriers. Therefore, those individuals that felt to demonstrate negative effects of insufficient sleep duration and/or quality should be encouraged to use sleep hygiene techniques, to improve daytime energy and alertness [10]. Longitudinal monitoring of training and match load, sleep, fatigue (e.g. trough HRV), stress, and mood may not only help identify individuals at risk but also can help monitor for improvements in sleep, well-being, and

performance during highly demanding competitions [64]. Thus, and in order to avoid high data loss, it is very important that coaches constantly encourage and explain to the players about the importance of monitoring load and health parameters (e.g. in areas such as player recovery) during different match and training constraints (e.g. international tournaments).

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References

1. King M, Duffield R. The effects of recovery interventions on consecutive days of intermittent sprint exercise. The Journal of Strength & Conditioning Research. 2009; 23(6):1795–802.
2. Andersson H, Bohn SK, Raastad T, Paulsen G, Blomhoff R, Kadi F. Differences in the inflammatory plasma cytokine response following two elite female soccer games separated by a 72-h recovery. Scandinavian journal of medicine & science in sports. 2010; 20:740–7. https://doi.org/10.1111/j.1600-0838.2009.00989.x PMID: 19765242.
3. Meeusen R, Duclos M, Foster C, Fry A, Gleeson M, Nieman D, et al. 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. Med Sci Sports Exerc. 2013; 45(1):186–205. https://doi.org/10.1249/MSS.0b013e318279a10a PMID: 23247672.
4. Roberts SSH, Teo WP, Warmington SA. Effects of training and competition on the sleep of elite athletes: a systematic review and meta-analysis. Br J Sports Med. 2018. https://doi.org/10.1136/bjsports-2018-099322 PMID: 30217831.
5. Fallon KE. Blood tests in tired elite athletes: expectations of athletes, coaches and sport science/sports medicine staff. Br J Sports Med. 2007; 41(1):41–4. https://doi.org/10.1136/bjsm.2006.030999 PMID: 17062653; PubMed Central PMCID: PMC2465134.

6. Watson NF, Badr MS, Belenky G, Bliwise DL, Buxton OM, Buysse D, et al. Recommended Amount of Sleep for a Healthy Adult: A Joint Consensus Statement of the American Academy of Sleep Medicine and Sleep Research Society. Sleep. 2015; 38(6):843–4. https://doi.org/10.5665/sleep.4716 PMID: 26039963; PubMed Central PMCID: PMC4434546.
7. Sargent C, Lastella M, Halson SL, Roach GD. The impact of training schedules on the sleep and fatigue of elite athletes. Chronobiol Int. 2014; 31(10):1160–8. https://doi.org/10.3109/07420528.2014.957306 PMID: 25222347.
8. Milewski MD, Skaggs DL, Bishop GA, Pace JL, Ibrahim DA, Wren TA, et al. Chronic lack of sleep is associated with increased sports injuries in adolescent athletes. J Pediatr Orthop. 2014; 34(2):129–33. https://doi.org/10.1097/BPO.0000000000000151 PMID: 25028798.
9. Lastella M, Roach GD, Halson SL, Sargent C. Sleep/wake behaviours of elite athletes from individual and team sports. Eur J Sport Sci. 2015; 15(2):94–100. https://doi.org/10.1080/17461391.2014.932016 PMID: 24993935.
10. Gupta L, Morgan K, Gilchrist S. Does Elite Sport Degrade Sleep Quality? A Systematic Review. Sports Med. 2017; 47(7):1317–33. https://doi.org/10.1007/s40279-016-0650-6 PMID: 27900583; PubMed Central PMCID: PMC5488138.
11. Lastella M, Roach GD, Sargent C. Travel fatigue and sleep/wake behaviors of professional soccer players during international competition. Sleep Health. 2019; 5(2):141–7. https://doi.org/10.1016/j.sleh.2018.10.013 PMID: 30928113.
12. Mah CD, Mah KE, Kezirian EJ, Dement WC. The effects of sleep extension on the athletic performance of collegiate basketball players. Sleep. 2011; 34(7):943–50. https://doi.org/10.5665/SLEEP.1132 PMID: 21731144; PubMed Central PMCID: PMC3119836.
13. Kolling S, Steinacker JM, Endler S, Ferrauti A, Meyer T, Kellmann M. The longer the better: Sleep-wake patterns during preparation of the World Rowing Junior Championships. Chronobiol Int. 2016; 33(1):73–84. https://doi.org/10.3109/07420528.2015.1118384 PMID: 26730643.
14. Claudino JG J Gabbet T, de Sá Souza H, Simim M, Fowler P, de Alcantara Borba D, et al. Which parameters to use for sleep quality monitoring in team sport athletes? A systematic review and meta-analysis. BMJ Open Sport & Exercise Medicine. 2019; 5(1):e000475. https://doi.org/10.1136/bmjsem-2018-000475 PMID: 30729029
15. Staunton C, Gordon B, Custovic E, Stanger J, Kingsley M. Sleep patterns and match performance in elite Australian basketball athletes. J Sci Med Sport. 2017; 20(8):786–9. https://doi.org/10.1016/j.jsams.2016.11.016 PMID: 28169152.
16. Ohayon M, Wickwire EM, Hirshkowitz M, Albert SM, Avidan A, Daly FJ, et al. National Sleep Foundation's sleep quality recommendations: first report. Sleep Health. 2017; 3(1):6–19. https://doi.org/10.1016/j.sleh.2016.11.006 PMID: 28346153.
17. Samuels C. Sleep, recovery, and performance: the new frontier in high-performance athletics. Neurol Clin. 2008; 26(1):169–80; ix-x. https://doi.org/10.1016/j.ncl.2007.11.012 PMID: 18295089.
18. Costa JA, Brito J, Nakamura FY, Figueiredo P, Oliveira E, Rebelo A. Sleep patterns and nocturnal cardiac autonomic activity in female athletes are affected by the timing of exercise and match location. Chronobiol Int. 2018:1–14. https://doi.org/10.1080/07420528.2018.1545782 PMID: 30451008.
19. Costa JA, Brito J, Nakamura FY, Oliveira EM, Costa OP, Rebelo AN. Does Night-Training Load Affect Sleep Patterns and Nocturnal Cardiac Autonomic Activity in High-Level Female Soccer Players? Int J Sports Physiol Perform. 2018:1–26. https://doi.org/10.1123/ijspp.2018-0652 PMID: 30569771.
20. Costa JA, Brito J, Nakamura FY, Oliveira EM, Rebelo AN. Effects of Late-Night Training on "Slow-Wave Sleep Episode" and Hour-by-Hour-Derived Nocturnal Cardiac Autonomic Activity in Female Soccer Players. Int J Sports Physiol Perform. 2018; 13(5):638–44. https://doi.org/10.1123/ijspp.2017-0681 PMID: 29345542.
21. Nedelec M, Aloulou A, Duforez F, Meyer T, Dupont G. The Variability of Sleep Among Elite Athletes. Sports Med Open. 2018; 4(1):34. https://doi.org/10.1186/s40798-018-0151-2 PMID: 30054756; PubMed Central PMCID: PMC6063976.
22. Van Dongen HP. Analysis of inter- and intra-individual variability. J Sleep Res. 2005; 14(2):201–3; author reply 5–6. https://doi.org/10.1111/j.1365-2869.2005.00453.x PMID: 15910519.
23. Buman MP, Hekler EB, Bliwise DL, King AC. Exercise effects on night-to-night fluctuations in self-rated sleep among older adults with sleep complaints. J Sleep Res. 2011; 20(1 Pt 1):28–37. https://doi.org/10.1111/j.1365-2869.2010.00866.x PMID: 20629937; PubMed Central PMCID: PMC2958223.
24. Breneman CB, Kline CE, West DS, Sui X, Porter RR, Bowyer KP, et al. The effect of moderate-intensity exercise on nightly variability in objectively measured sleep parameters among older women. Behav Sleep Med. 2017:1–11. https://doi.org/10.1080/15402002.2017.1395337 PMID: 29053410; PubMed Central PMCID: PMC6157002.

25. Fullagar HH, Skorski S, Duffield R, Hammes D, Coutts AJ, Meyer T. Sleep and athletic performance: the effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. Sports Med. 2015; 45(2):161–86. https://doi.org/10.1007/s40279-014-0260-0 PMID: 25315456.

26. Plews DJ, Laursen PB, Buchheit M. Day-to-Day Heart-Rate Variability Recordings in World-Champion Rowers: Appreciating Unique Athlete Characteristics. Int J Sports Physiol Perform. 2017; 12(5):697–703. https://doi.org/10.1123/ijspp.2016-0343 PMID: 27736257.

27. Achten J, Jeukendrup AE. Heart rate monitoring: applications and limitations. Sports Med. 2003; 33 (7):517–38. https://doi.org/10.2165/00007256-200333070-00004 PMID: 12762827.

28. Boullosa DA, Abreu L, Nakamura FY, Munoz VE, Dominguez E, Leicht AS. Cardiac autonomic adaptations in elite Spanish soccer players during preseason. Int J Sports Physiol Perform. 2013; 8(4):400–9. PMID: 23170746.

29. Brandenberger G, Buchheit M, Ehrhart J, Simon C, Piquard F. Is slow wave sleep an appropriate recording condition for heart rate variability analysis? Auton Neurosci. 2005; 121(1–2):81–6. https://doi.org/10.1016/j.autneu.2005.06.002 PMID: 16005265.

30. Pichot V, Roche F, Gaspoz JM, Enjolras F, Antoniadis A, Minini P, et al. Relation between heart rate variability and training load in middle-distance runners. Med Sci Sports Exerc. 2000; 32(10):1729–36. https://doi.org/10.1097/00005768-200010000-00011 PMID: 11039645.

31. Michael S, Jay O, Graham KS, Davis GM. Influence of exercise modality on cardiac parasympathetic and sympathetic indices during post-exercise recovery. J Sci Med Sport. 2018; 21(10):1079–84. https://doi.org/10.1016/j.jsams.2018.01.015 PMID: 29449080.

32. Costa JA, Brito J, Nakamura FY, Oliveira EM, Rebelo AN. Effects of Late-Night Training on "Slow-Wave Sleep Episode" and Hour-by-Hour Derived Nocturnal Cardiac Autonomic Activity in Female Soccer Players. Int J Sports Physiol Perform. 2018:1–26. https://doi.org/10.1123/ijspp.2017-0681 PMID: 29345542.

33. Al Haddad H, Laursen PB, Ahmaidi S, Buchheit M. Nocturnal heart rate variability following supramaximal intermittent exercise. Int J Sports Physiol Perform. 2009; 4(4):435–47. PMID: 20029095.

34. Mann TN, Lamberts RP, Lambert MI. High responders and low responders: factors associated with individual variation in response to standardized training. Sports Med. 2014; 44(8):1113–24. https://doi.org/10.1007/s40279-014-0197-3 PMID: 24807838.

35. Halson SL. Monitoring training load to understand fatigue in athletes. Sports Med. 2014; 44 Suppl 2: S139–47. https://doi.org/10.1007/s40279-014-0253-z PMID: 25200666; PubMed Central PMCID: PMC4213373.

36. Buchheit M. Monitoring training status with HR measures: do all roads lead to Rome? Front Physiol. 2014; 5:73. https://doi.org/10.3389/fphys.2014.00073 PMID: 24578692; PubMed Central PMCID: PMC3936188.

37. de Freitas VH, Pereira LA, de Souza EA, Leicht AS, Bertollo M, Nakamura FY. Sensitivity of the Yo-Yo Intermittent Recovery Test and cardiac autonomic responses to training in futsal players. Int J Sports Physiol Perform. 2015; 10(5):553–8. https://doi.org/10.1123/ijspp.2014-0365 PMID: 25405584.

38. Nakamura FY, Antunes P, Nunes C, Costa JA, Esco MR, Travassos B. Heart Rate Variability Changes From Traditional vs. Ultra–Short-Term Recordings in Relation to Preseason Training Load and Performance in Futsal Players. J Strength Cond Res. 2018;XX(X)(000–000).

39. Flatt AA, Esco MR. Smartphone-Derived Heart-Rate Variability and Training Load in a Women's Soccer Team. Int J Sports Physiol Perform. 2015; 10(8):994–1000. https://doi.org/10.1123/ijspp.2014-0556 PMID: 25756657.

40. Buchheit M, Mendez-Villanueva A, Quod MJ, Poulos N, Bourdon P. Determinants of the variability of heart rate measures during a competitive period in young soccer players. Eur J Appl Physiol. 2010; 109 (5):869–78. https://doi.org/10.1007/s00421-010-1422-x PMID: 20229253.

41. Flatt AA, Esco MR. Evaluating Individual Training Adaptation With Smartphone-Derived Heart Rate Variability in a Collegiate Female Soccer Team. J Strength Cond Res. 2016; 30(2):378–85. https://doi.org/10.1519/JSC.0000000000001095 PMID: 26200192.

42. Nakamura FY, Pereira LA, Rabelo FN, Flatt AA, Esco MR, Bertollo M, et al. Monitoring weekly heart rate variability in futsal players during the preseason: the importance of maintaining high vagal activity. J Sports Sci. 2016; 34(24):2262–8. https://doi.org/10.1080/02640414.2016.1186282 PMID: 27214584.

43. Juliff LE, Halson SL, Hebert JJ, Forsyth PL, Peiffer JJ. Longer Sleep Durations Are Positively Associated With Finishing Place During a National Multiday Netball Competition. J Strength Cond Res. 2018; 32(1):189–94. https://doi.org/10.1519/JSC.0000000000001793 PMID: 28135218.

44. Beato M, Coratella G, Stiff A, Iacono AD. The Validity and Between-Unit Variability of GNSS Units (STATSports Apex 10 and 18 Hz) for Measuring Distance and Peak Speed in Team Sports. Front

Physiol. 2018; 9:1288. https://doi.org/10.3389/fphys.2018.01288 PMID: 30298015; PubMed Central PMCID: PMC6161633.

45. Gaudino P, Iaia FM, Alberti G, Hawkins RD, Strudwick AJ, Gregson W. Systematic bias between running speed and metabolic power data in elite soccer players: influence of drill type. Int J Sports Med. 2014; 35(6):489–93. https://doi.org/10.1055/s-0033-1355418 PMID: 24165959.

46. Scott D, Lovell R. Individualisation of speed thresholds does not enhance the dose-response determination in football training. J Sports Sci. 2018; 36(13):1523–32. https://doi.org/10.1080/02640414.2017.1398894 PMID: 29099673.

47. Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, et al. A new approach to monitoring exercise training. J Strength Cond Res. 2001; 15(1):109–15. PMID: 11708692.

48. Alsaadi SM, McAuley JH, Hush JM, Bartlett DJ, McKeough ZM, Grunstein RR, et al. Assessing sleep disturbance in low back pain: the validity of portable instruments. PLoS One. 2014; 9(4):e95824. https://doi.org/10.1371/journal.pone.0095824 PMID: 24763506; PubMed Central PMCID: PMC3998977.

49. Sadeh A, Sharkey KM, Carskadon MA. Activity-based sleep-wake identification: an empirical test of methodological issues. Sleep. 1994; 17(3):201–7. https://doi.org/10.1093/sleep/17.3.201 PMID: 7939118.

50. Parak J, Korhonen I. Accuracy of Firstbeat BodyGuard 2 beat-to-beat heart rate monitor. https://www.firstbeat.com/app/uploads/2015/10/white_paper_bodyguard2_final.pdf. Accessed May 8, 2017. 2015.

51. TaskForce. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Circulation. 1996; 93(5):1043–65. PMID: 8598068.

52. Mourot L, Bouhaddi M, Perrey S, Cappelle S, Henriet MT, Wolf JP, et al. Decrease in heart rate variability with overtraining: assessment by the Poincare plot analysis. Clin Physiol Funct Imaging. 2004; 24 (1):10–8. PMID: 14717743.

53. Akaike H. A new look at the statistical model identification. IEEE Transactions on Automatic Control. 1974; 19:716–23.

54. Bland JM, Altman DG. Calculating correlation coefficients with repeated observations: Part 1—Correlation within subjects. BMJ. 1995; 310(6977):446. https://doi.org/10.1136/bmj.310.6977.446 PMID: 7873953; PubMed Central PMCID: PMC2548822.

55. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009; 41(1):3–13. https://doi.org/10.1249/MSS.0b013e31818cb278 PMID: 19092709.

56. Fullagar HH, Skorski S, Duffield R, Julian R, Bartlett J, Meyer T. Impaired sleep and recovery after night matches in elite football players. J Sports Sci. 2016; 34(14):1333–9. https://doi.org/10.1080/02640414.2015.1135249 PMID: 26750446.

57. Nédélec M, Dawson B, Dupont G. Influence of night soccer matches on sleep in elite players. J Strength Cond Res. 2018;(XX(X)):000–.

58. Fullagar H, Skorski S, Duffield R, Meyer T. The effect of an acute sleep hygiene strategy following a late-night soccer match on recovery of players. Chronobiol Int. 2016; 33(5):490–505. https://doi.org/10.3109/07420528.2016.1149190 PMID: 27031035.

59. Sargent C, Roach GD. Sleep duration is reduced in elite athletes following night-time competition. Chronobiol Int. 2016; 33(6):667–70. https://doi.org/10.3109/07420528.2016.1167715 PMID: 27097227.

60. Vuori I, Urponen H, Hasan J, Partinen M. Epidemiology of exercise effects on sleep. Acta Physiol Scand Suppl. 1988; 574:3–7. PMID: 3245463.

61. Sargent C, Halson S, Roach GD. Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. Eur J Sport Sci. 2014; 14 Suppl 1:S310–5. https://doi.org/10.1080/17461391.2012.696711 PMID: 24444223.

62. Van Dongen HP, Maislin G, Mullington JM, Dinges DF. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep. 2003; 26(2):117–26. https://doi.org/10.1093/sleep/26.2.117 PMID: 12683469.

63. Kolling S, Duffield R, Erlacher D, Venter R, Halson SL. Sleep-related Issues for Recovery and Performance in Athletes. Int J Sports Physiol Perform. 2018:1–17. https://doi.org/10.1123/ijspp.2017-0746 PMID: 29651858.

64. Simpson NS, Gibbs EL, Matheson GO. Optimizing sleep to maximize performance: implications and recommendations for elite athletes. Scand J Med Sci Sports. 2017; 27(3):266–74. https://doi.org/10.1111/sms.12703 PMID: 27367265.

65. Milner CE, Cote KA. Benefits of napping in healthy adults: impact of nap length, time of day, age, and experience with napping. J Sleep Res. 2009; 18(2):272–81. https://doi.org/10.1111/j.1365-2869.2008.00718.x PMID: 19645971.

66. Esco MR, Snarr RL, Flatt A, Leatherwood M, Whittaker A. Tracking changes in maximal oxygen consumption with the heart rate index in female collegiate soccer players. J Hum Kinet. 2014; 42:103–11. https://doi.org/10.2478/hukin-2014-0065 PMID: 25414744; PubMed Central PMCID: PMC4234749.

67. Flatt AA, Esco MR, Nakamura FY, Plews DJ. Interpreting daily heart rate variability changes in collegiate female soccer players. J Sports Med Phys Fitness. 2017; 57(6):907–15. https://doi.org/10.23736/S0022-4707.16.06322-2 PMID: 26997322.

68. Flatt AA, Hornikel B, Esco MR. Heart rate variability and psychometric responses to overload and tapering in collegiate sprint-swimmers. J Sci Med Sport. 2017; 20(6):606–10. https://doi.org/10.1016/j.jsams.2016.10.017 PMID: 27890479.

69. Flatt AA, Esco MR, Nakamura FY. Individual Heart Rate Variability Responses to Preseason Training in High Level Female Soccer Players. J Strength Cond Res. 2017; 31(2):531–8. https://doi.org/10.1519/JSC.0000000000001482 PMID: 27227794.

70. Bellenger CR, Karavirta L, Thomson RL, Robertson EY, Davison K, Buckley JD. Contextualizing Parasympathetic Hyperactivity in Functionally Overreached Athletes With Perceptions of Training Tolerance. Int J Sports Physiol Perform. 2016; 11(7):685–92. https://doi.org/10.1123/ijspp.2015-0495 PMID: 26640275.

71. Watson AM. Sleep and Athletic Performance. Curr Sports Med Rep. 2017; 16(6):413–8. https://doi.org/10.1249/JSR.0000000000000418 PMID: 29135639.

Study 5

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Using the Rating of Perceived Exertion and Heart Rate to Quantify Training Intensity in Female Soccer Players: Validity and Utility

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Abstract

Costa, JA, Brito, J, Nakamura, FY, Figueiredo, P, and Rebelo, A. Using the rating of perceived exertion and heart rate to quantify training intensity in female soccer players: validity and utility. *J Strength Cond Res* XX(X): 000–000, 2019—The aims of this study were as follows: (a) to analyze associations between session rating of perceived exertion (sRPE) and training impulse (TRIMP); (b) to verify whether significantly different ranges of percentage of heart rate peak (%HRpeak) would be reached in each discrete RPE category; and (c) to investigate the amount of time spent >90% of HRpeak and associated intraplayer and interplayer variability during soccer technical training sessions with similar contents and duration. This was a single-group observational study that measured the internal training load during 6 weeks of the competitive period in 17 high-level female soccer players. All training sessions started around 9 PM. and lasted on average 94 ± 5 minutes. During each training session, RPE, sRPE, TRIMP, HRex (% HRpeak), and time spent at >90% of HRpeak were assessed. A very large correlation was found between sRPE and TRIMP (r = 0.78; 95% confidence interval: [0.74–0.82]). Significant differences were observed between %HRpeak associated with each RPE value (i.e., RPE = 2 arbitrary unit [68%; 65–69% of %HRpeak]; RPE 3 [72%; 69–75%]; RPE 4 [79%; 76–82%]; RPE 5 [84; 81–87%]; χ^2 = 73.34; df = 3; $P < 0.001$). Intraplayer and interplayer coefficients of variation for the time spent >90% of HRpeak (~8% of training time, ~7 minutes per session) during training sessions were 73 and 92%, respectively. In conclusion, it was confirmed that sRPE and TRIMP displayed good convergent validity, and different %HRpeak were observed for each discrete RPE. However, because of the high variability in the time >90% of HRpeak, careful monitoring of individual exercises should be performed to ensure the desired training stimulus for each player.

Key Words: training monitoring, internal load, physical training, team sports

Introduction

Although the neurophysiology underlying perception of effort during exercise is rather complex, it is becoming accepted that it arises from the corollary discharge of the central motor command, which is processed by the sensory areas of the brain (13,29). Rating of perceived exertion (RPE) is directly related to exercise intensity (34), but factors such as peripheral muscle fatigue (30) and mental fatigue (31) can influence its magnitude and affect exercise tolerance and performance. In this context, differential RPE—separate scores for breathlessness, leg muscle exertion, and technical/cognitive exertion, may be a viable alternative for the measurement of internal loads, as recently shown (6). In practice, RPE is an easy, low-cost way to quantify task intensity as it relies solely on a valid rating scale (8). For this reason, the RPE is widely used across several sports settings.

Session RPE (sRPE) is the product of RPE for the entire training session (usually taken 15–30 minutes after its completion (40)) and its respective duration (15). The literature contains wide support for the construct validity of sRPE (11,22,24,25,36). For instance, sRPE is largely to very largely correlated with training impulse (TRIMP)—a heart rate–derived method to quantify the internal training load (9). In soccer, studies have shown individual correlations (sRPE vs. TRIMP) ranging between 0.50 and 0.77 in men and between 0.67 and 0.95 in women (22) when using the Banister (5) equation to calculate TRIMP. Both sRPE and TRIMP are heavily influenced by the duration of the training session. Therefore, these correlations can be inflated by the fact that both sRPE and TRIMP consider the same training volume in their estimation.

It is imperative to note that previous studies relating sRPE and TRIMP have used Pearson's product-moment correlations. However, it is also important in longitudinal studies to quantify intraindividual correlations following the most appropriate statistical approach which models the longitudinal data set as a whole using the correct degrees of freedom. For instance, rather than pooling all the data, or calculating correlations separately for individual subjects, this approach quantifies the correlation, and associated 95% confidence interval (95% CI), between a covariate and outcome while taking into account the within-subject nature of the study design (3,7,26). For example, in research conducted by Kelly et al. (24), the authors found a high within-subject correlation between sRPE and TRIMP for estimating training load in elite male soccer players across a typical in-season competitive phase. Accordingly, the authors suggested

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that sRPE is a simple and practical global indicator of individual training load in elite-level soccer players and can reflect the internal training load stressors elicited on individual players. This finding needs to be confirmed in other populations (e.g., female soccer players).

Apart from the expected association between sRPE and TRIMP, evidence suggests that the respective intensity indicators (RPE and HR) might not be highly correlated (i.e., individual analysis using Pearson's *r*) during typical high-intensity team sport drills (27,42). However, one should test whether, at a group level, different ranges of cardiovascular demands during training can be demarcated by each numerical category of RPE using the category ratio scale proposed by Borg (8). In other words, associated with different integral RPE values, significantly different values of HR should be found, even considering the interindividual HR response variability (i.e., interquartile intervals) within a squad of highly trained players. This knowledge may help coaches in the use of RPE to provide an estimate of the cardiovascular demand of a given training session.

Apart from allowing the calculation of TRIMP, HR monitoring during soccer training sessions can also be used to predict training adaptations. For instance, the time spent at intensities >90% of HRpeak was largely correlated with changes in aerobic fitness in male professional soccer players (12). It has been suggested that 6–8% of total training time should be devoted to around 90–95% of HRpeak to elicit cardiorespiratory changes (12). Few studies have been conducted with female soccer players reporting the amount of time spent at different ranges of HR (38). Furthermore, a single study has shown that female players spent more than 60% of the time during small-sided games (SSG) at HR >85% of HRpeak (28). To the best of our knowledge, there are no reports on the proportion of training time spent >90% of HRpeak and its intraindividual and interindividual variability in female soccer players, which is recommended to induce changes in endurance (21). High levels of variability in the time spent >90% of HRpeak demand attention from technical staff to better prescribe appropriate training sessions to avoid insufficient or excessive load to the players.

This study aimed to investigate the association (within-subject correlation) between sRPE and TRIMP in high-level female soccer players, using training sessions with similar contents (i.e., technical training with ball involvement) and duration. We also aimed to verify whether significantly different ranges of %HRpeak would be reached in each RPE category; this comparison would allow for testing of whether RPE (i.e., exercise intensity) can discriminate different cardiovascular demands during soccer drills even after disregarding training volume (i.e., duration). Finally, we also intended to investigate the amount of time spent >90% of HRpeak and associated intraplayer and interplayer variability during technical training sessions in female soccer.

Methods

Experimental Approach to the Problem

This was a single-group observational study that measured internal training load during 6 weeks of the competitive period in high-level female soccer players. Eighteen training days were analyzed in 17 players (goalkeepers were excluded). All training sessions (Monday, Wednesday, and Friday) started around 9 *p*.m. (21:10 ± 00:21 hours; mean ± *SD*) and lasted on average 94 ± 5 minutes (range: 89–99 minutes), with competitive matches played each Sunday (started around 3 PM). The training sessions were planned by the coach, throughout the season, which consistently primarily of warm-up and activation (whole-body workouts involving power cleans and squats and the 11 + injury prevention program (39)); technical training (i.e., skill development with ball control and dribblings); and SSG (format 4 vs. 4 without goalkeepers); scrim = scrimmages (11 vs. 11 with goalkeepers) (Table 1). It is important to highlight that training sessions proposed by the coaching staff were very consistent across the days during the observation period. It was a characteristic of the team, but at the same time, it was also carefully planned (by the coaching staff and the research team) with the intention to maintain the duration of each section of the training session during the study, to standardize the research observation.

Within-subject associations between sRPE and TRIMP and comparisons between %HRpeak reached for each RPE category were also performed. In addition, intraplayer and interplayer variability values for the RPE, sRPE, TRIMP, %HRpeak, and time spent at >90% of HRpeak were computed. During 5 weeks before the study, the players were familiarized with the tools to be used during the investigation to avoid disturbance of training activities by extraneous equipment. All athletes attended 100% of the training sessions during the observation period. All training sessions were performed on an outdoor artificial turf pitch, which was the usual training venue for the players. Ambient temperature ranged between 18 and 20° C.

Subjects

Seventeen high-level female soccer players (4 central defenders, 6 midfielders, 3 fullbacks, and 4 attackers; mean ± *SD*; age: 21.4 ± 2.1 years; height: 163.3 ± 5.9 cm; body mass: 57.7 ± 5.7 kg) competing in the first division of the Portuguese championship participated in the study. The study design was carefully explained to the athletes, and written informed consent was obtained. The study followed the Declaration of Helsinki and was approved by the ethics committee of the Faculty of Sports, University of Porto (CEFADE 03.2017). All subjects had the medical approval to participate in the study and reported not to take any medication during the study.

Procedures

One week before the commencement of data collection, the subjects completed a Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1). The Yo-Yo IR1 is a high-intensity intermittent exercise performance test, specially developed to evaluate game-specific physical capacities of soccer players (4). The test consists of repeated 2 × 20-m runs (shuttles) back and forth between the start and finish line at progressively increased speeds, controlled by audio bleeps from a tape recorder. After each shuttle, the players were instructed to jog/walk during 10 seconds over 5 m (active recovery) in a space delimited between 2 cones. The aim of the test was to perform as many shuttles as possible. When the player failed twice to reach the finish line in time, the distance covered and peak HR were recorded and used as the test result. Only 1 trial was allowed, but subjects were verbally motivated to give their maximal effort. During the test, the subjects wore HR monitors (Firstbeat Sports, Finland). The peak HR obtained by the players during the Yo-Yo IR1 test (194 ± 4 b·min^{-1}) was confirmed through the age-predicted peak HR (195 ± 3 b·min^{-1}) as calculated from the 220-age equation (16).

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Table 1
Typical weekly training program for the female soccer players.*

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Training wk	Warm-up and activation∼10′	Rest	Warm-up and activation∼10′	Rest	Warm-up and activation∼10′	Rest	Match ∼90′
	Resting 1–2′		Resting 1–2′		Resting 1–2′		
	TEC ∼10′		TEC ∼10′		TEC ∼10′		
	Resting 1–2′		Resting 1–2′		Resting 1–2′		
	SSG ∼20′		SSG ∼20′		SSG ∼20′		
	Resting 1–2′		Resting 1–2′		Resting 1–2′		
	Scrim ∼50′		Scrim ∼50′		Scrim ∼50′		

*Warm-up and activation = whole-body workouts involving power cleans and squats; resting = period of hydration; TEC = technical training (i.e., skill development); SSG = small-sided games (format 4 vs. 4); scrim = scrimmages (11 vs. 11).

HR data during training sessions were recorded at 5-s intervals by short-range radio telemetry (Firstbeat Sports, Jyväskylä, Finland). The monitors were attached to the subjects using an adjustable elastic chest strap. Data were transferred to a computer using the corporative software Firstbeat Sports Server version 4.7.3.1. HRpeak, which was considered as the highest value reached during the Yo-Yo IR1, was used as a standard against which to define the intensity zone at >90% HRpeak. The software quantified the time spent at this intensity zone (>90% HRpeak) during training sessions, and data were presented as the percentage relative to the total training time. The software also calculated the HRex, which was expressed in absolute values ($b \cdot min^{-1}$) and as the percentage relative to the individual HRpeak (%HRpeak) for the intensity zone as mentioned previously. The HR recording was not interrupted during the breaks (e.g., transition between consecutive training sections) because the coaching staff organized the training setting so that these breaks were not longer than 1 minute.

Training impulse was calculated according to the Bannister et al. (5) formula:

$$\text{TRIMP} = T \times [(\text{HRex} - \text{HRrest})/(\text{HRpeak} - \text{HRrest})] \times 0.86e^{1.67[(\text{HRex} - \text{HRrest})/\text{HRpeak} - \text{HRrest}]}$$

where T is the duration of the workout in minutes; HRex is the average HR during exercise ($b \cdot min^{-1}$); HRrest, the average HR during rest ($b \cdot min^{-1}$), measured during 5 minutes of seated rest (after 5 minutes of stabilization period in the same position (33)) before starting each training session in the study period (1), HRpeak, determined as the highest value reached during the Yo-Yo IR1 test, and e∼2.718.

The RPE was obtained approximately 15–30 minutes after each training session due to the coach's preference and to the fact that players were familiarized to indicate RPE using this timing. In fact, the canonical procedures for sRPE assessment suggested to respect a time delay of ∼15–30 minutes after training to promote an unbiased training intensity perception in athletes (40). The sRPE was determined by multiplying the Borg CR-10 scale (8) modified by Foster et al. (15) by the duration of the training session. Each player's sRPE was collected in private, to avoid the potential effects of peer pressure or influence after each training session.

Statistical Analyses

Data are expressed as means ± *SD*. Within-subject correlations were calculated between the sRPE and TRIMP (7). Rather than pooling all the data or calculating correlations separately for individual subjects, this approach quantifies the correlation, and associated 95% CI, between a covariate and outcome while taking into account the within-subject nature of the study design. This longitudinal modeling approach is based on the correct number of degrees of freedom and is therefore associated with higher statistical precision for individual players. Intraplayer and interplayer variability for the RPE, sRPE, TRIMP, %HRpeak, and time spent >90% of HRpeak for all training sessions were analyzed using the coefficient of variation (CV). To interpret the magnitude of correlation between the 2 variables (sRPE and TRIMP), the following criteria were applied: ($r < 0.1$) trivial, ($0.1 < r < 0.3$) small, ($0.3 < r < 0.5$) moderate, ($0.5 < r < 0.7$) large, ($0.7 < r < 0.9$) very large, ($r > 0.9$) almost perfect, and ($r = 1$) perfect (41). For nonparametric data (i.e., %HRpeak for each RPE category), comparisons were examined using a Friedman test and Wilcoxon post hoc test.

Results

The performance of subjects in the Yo-Yo IR1 test was 904 ± 239 m and the overall training load indices across the observed sessions (lasting on average 94 ± 5 minutes [range: 89–99 minutes]) were 139 ± 12 $b \cdot min^{-1}$ for HRex; sRPE: 338 ± 107 AU; TRIMP: 211 ± 81 AU; RPE: 3.2 (1.0) AU (median [interquartile range]); %HRpeak: 73.1 (6.2)%, and relative time spent >90% of HRpeak: 8.3 ± 7.7% of total training time (∼7 minutes per session). Within-subject correlations between sRPE and TRIMP are outlined in Figure 1, whereas comparisons between % HRpeak reached for each RPE category are outlined in Figure 2. Very large correlations were found between sRPE and TRIMP ($r = 0.78$; 95% CI: [0.74–0.82]; $P < 0.001$). Comparisons resulted in significant differences in %HRpeak between each RPE numerical category (i.e., RPE 2, easy [68%; 65–69% of %HRpeak]; RPE 3, moderate [72%; 69–75%]; RPE 4, somewhat hard [79%; 76–82%]; RPE 5, hard [84; 81–87%]; median and interquartile intervals; $\chi^2 = 73.34$; df = 3; $P < 0.001$).

Intraplayer and interplayer coefficients of variation for the RPE, sRPE, TRIMP, %HRpeak, and time spent >90% of HRpeak for all training sessions are outlined in Table 2 Intraplayer and interplayer variability during training sessions for RPE were 26.7 and 29.2%; sRPE: 31.2 and 31.7%; TRIMP: 31.5 and 38.5%; %HRpeak: 17.0 and 18.8%, and time spent at >90% of HRpeak: 73.3 and 92.2%, respectively.

Discussion

The findings of this study support the convergent validity between sRPE and TRIMP, using the appropriate within-subject correlation to analyze longitudinal data from a female soccer team, associated with a higher statistical precision for individual players.

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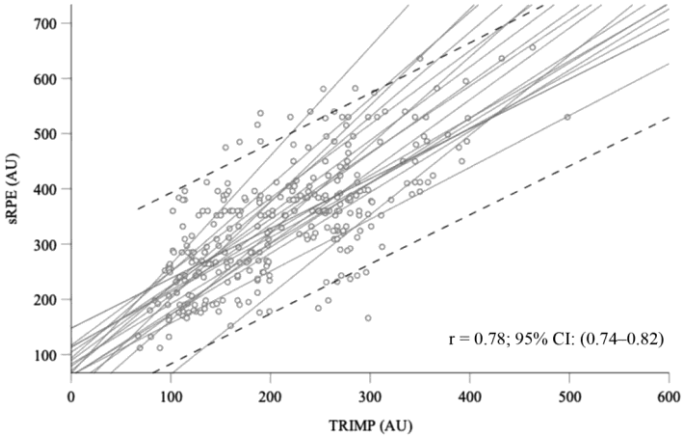


Figure 1. Relationship between session rating of perceived exertion (sRPE) and training impulse (TRIMP) during training sessions in female soccer players ($r = 0.78$; $P < 0.001$). Dashed black lines represent the associated within-subject correlations with 95% confidence interval (95% CI: [0.74–0.82]).

More importantly, different discrete values of RPE from the CR-10 scale were associated with significantly different HR values, suggesting that a rise of 1 point on the scale represents a meaningful change in the objectively determined exercise intensity. Furthermore, this study found that although female soccer players spent adequate time >90% of HRpeak (12) during training sessions, there is great intraplayer and interplayer variability in this response.

Mismanagement of training load in team sports increases the risk of overreaching/injury when it is too high or the risk of understimulation and loss of performance due to detraining when it is too low. This is the main reason for finely monitoring internal training load using valid and reliable methods on an individual basis which can inform training prescription. The use of unobtrusive and cost-effective RPE scales across training and competition settings—compared with microtechnology sensors such as heart rate monitors—has been spreading in team sports.

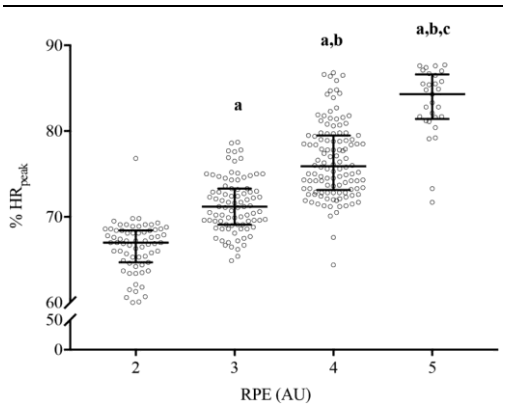


Figure 2. Comparisons between %HRpeak of each rating of the perceived exertion (RPE) score during 18 training sessions in female soccer players (black lines represent median and interquartile intervals; gray dots represent all individual RPE classifications for each RPE score); $\chi^2 = 73.34$; df = 2; $P < 0.001$. [a]Significantly different compared with %HRpeak of RPE = 2 AU (easy); [b]significantly different compared with % HRpeak of RPE = 3 AU (moderate); [c]significantly different compared with %HRpeak of RPE = 4 AU (somewhat hard).

Therefore, it has become a common practice to validate sRPE as a measure of internal training load by testing its correlation with TRIMP and measures of external load (32). A previous study assessing the association between sRPE and TRIMP in female soccer players across different training modes (matches and conditioning, speed, resistance and technical sessions) revealed that in all the individual cases, the correlation was significant ($r = 0.67–0.95$) (1). This is comparable with the within-subject results obtained in our study (17 players), which presented significant correlations between sRPE and TRIMP ($r = 0.78$; 95% CI: [0.74–0.82]; $P < 0.001$). Therefore, our results indicate that sRPE is acceptably valid in players of a highly trained soccer squad and also that measurement of HR can provide an additional objective evaluation of internal load (22,38) as both metrics share "only" ~61% of the variance. In younger male soccer players, this shared variance is lower (~50%) (22), possibly because of age and training experience. It remains to be determined whether educating players to use perception of effort scales (e.g., anchoring of lower and upper levels of effort) (20) or using finer graded scales (i.e., CR100) (14) can help players to more accurately rate their effort regarding their physiological responses. Furthermore, because sRPE and TRIMP are highly and similarly correlated with measures of external load in soccer (e.g., player load), they both can arguably be used to quantify internal responses to a session (11).

In addition, players seemed to demonstrate acceptable levels of accuracy while reporting RPE because it was observed that within the range of values obtained during the technical training sessions, rising 1 point in the scale resulted in a significantly higher HR (i.e., %HRpeak) value (RPE 2 [68%; 65–69%]; RPE 3 [72%; 69–75%]; RPE 4 [79%; 76–82%]; RPE 5 [84; 81–87%], median and interquartile intervals of %HRpeak). In other words, the level of precision of the scale (1 point) is associated with a specific range of HR values. With this knowledge, coaches can estimate the cardiovascular demands of a given soccer training session using the RPE scale, which is costless to implement. Other studies must determine whether these values can be generalized to other samples of female athletes because it could help fitness trainers to estimate the cardiovascular load of a given training session based on the post-training RPE value. Furthermore, the necessity to extend our findings in the range of RPE values >5 in this and

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Table 2

Intraplayer and interplayer variability (coefficient of variation, CV%) for the rating of perceived exertion (RPE), session-RPE (sRPE), training impulse (TRIMP), the average HR during exercise (HRex) as the percentage relative to the individual peak HR (%HRpeak) and for the time spent >90% of HRpeak, during training sessions in female soccer players.*

	RPE	sRPE	TRIMP	%HRpeak	>90% HRpeak
Intraindividual variability	26.7%	31.2%	31.5%	17.0%	73.4%
Interindividual variability	29.2%	31.7%	38.5%	18.8%	92.2%
Range	1–6 AU	112–656 AU	67–498 AU	59.4–87.7%	0.9–41.6%
Mean ± *SD* or median (interquartile range)	3.2 (1.0) AU	338 ± 107 AU	211 ± 81 AU	73.1 (6.2) %	8.4 ± 7.7%
95% CI	3.2–3.5	326–350	202–220	72.6–74.1	7.5–9.2

*CI = confidence interval.

other populations of athletes is clear because we have only included training sessions with RPE varying between 2 and 5. In this sense, other training modes (e.g., high-intensity interval training, repeated sprint training, extensive technical drills, etc) need to be included in the observations.

According to Algroy et al. (2), RPE between 1 and 4 indicates that the average training intensity is below the first ventilatory threshold (VT1), the so-called zone 1. The median RPE of our group was 3.2 (1.0) AU, which agrees with the relatively low mean HRex during the training sessions (73.1 [6.2] % of HRpeak). In fact, in the referred study, male professional soccer players spent between 71 and 73% of their training time below VT1. These values are probably explained due to the presence of a warm-up, short breaks, and pauses for instruction from the coach, besides a cool down phase, all of which contribute to a relatively low intensity of training, especially when HR and RPE refer to the entire session. In spite of this, our results also reveal that, on average, female players spend ~8% of training time at HR >90% of HRpeak (resulting in ~7 minutes per session). This is within the recommendations in soccer to improve aerobic fitness as Castagna et al. (12) have previously shown that achieving 7–8% of training time at HR >90% of HRpeak was capable of significantly increasing aerobic fitness (lactate threshold and maximal oxygen consumption) of elite male soccer players. Training less was deemed to be insufficient to elicit such changes according to a correlational analysis (12). However, it is important to emphasize that time spent at HR >90% of HRpeak was quite variable in intraplayers and interplayers. The respective CV % values were 73.3 and 92.2%, and data had a minimum and maximum of 0.94 and 41.6% of training time. These results suggest that technical staff should be encouraged to monitor HR during training sessions to better adjust training loads and strategies to adequately stimulate the cardiorespiratory responses of all players. A good strategy could be prescribing high-intensity interval training using standard field tests to elicit known cardiovascular responses (i.e., >90% of HRpeak) (10,21) to those players accumulating a short time period >90% of HRpeak during technical training, especially when the aim of the training is to achieve high physiological strain together with skills acquisition (19). In fact, in our sample, some players accumulated close to 0 minutes at >90% of HRpeak in some training sessions. Lack of high-intensity training can lead to detraining and impair physical performance (23). It is important to note that the very-high interplayer variability in the time spent >90% of HRpeak can be heavily influenced by the respective playing positions due to their different physical demands during match-play (17,35) and training sessions (18).

This study has some limitations to be considered. Owing to the initial purposes, we have selected a period in which training sessions were relatively homogeneous in terms of intensity and duration so that training contents (e.g., different SSG formats [1 vs. 1]) eliciting greater cardiorespiratory and perceptual demands were not included. The findings need to be confirmed in higher intensity training sessions (i.e., HR range for >5 RPE) encompassing other training modes (e.g., high-intensity interval training or more extensive skill-based training). In addition, the eventual effect of the residual fatigue (especially on Monday's training session) caused by playing the weekly match was not controlled for in the current study as players had dissimilar participation times (from 0 to 90 minutes), and this aspect can influence sRPE and TRIMP (37). Therefore, we recognize it as an important limitation of this study. Finally, we emphasize that because individual characteristics (e.g., aerobic fitness) can influence the relationship between RPE and HR, our results cannot be generalized to other samples of soccer players. Actually, we encourage each team to develop its own ranges of HR corresponding to the values of RPE to better estimate the internal training load using the latter.

In conclusion, we confirmed in female soccer players the previously reported convergent validity of sRPE and TRIMP using appropriate statistical analysis (24). Furthermore, knowledge of the correspondence between discrete levels of RPE and the range of HR variation within each RPE unit could help coaches to monitor the cardiovascular load of training practices using the subjective response. Finally, during technical training sessions, soccer players present very high variability in the time spent >90% of HRpeak, although, on average, they tend to reach adequate relative values (6–8%) to improve (or maintain) their aerobic fitness.

Practical Applications

The sRPE method has been proved to be a simple but effective way to quantify the internal training load. In fact, the current study confirms the high association between sRPE and HR-based TRIMP, supporting the use of the former when HR devices are not available to the team. Even in the absence of HR recordings, our results provide the coaches with specific ranges of %HRpeak expected to be reached in each RPE category from 2 to 5 (in players with similar characteristics to ours), encompassing easy to hard training sessions, in female soccer players. However, although the sRPE method may be simple, valid, and reliable, the addition of HR monitoring may aid in the interpretation of the internal load provided to the players because the shared variance amounts to "only" ~61%. Moreover, monitoring the amount of high-intensity work in the time spent above 90% of HRpeak could be

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Chapter IV

General discussion and conclusions

5. General discussion

5.1. Sleep and cardiac autonomic activity: the impact of training and match schedule and load, and match location in female soccer players

Sport training is characterized by the correct distribution of intensity (i.e., load), duration, and frequency of training stimuli (Clemente-Suarez et al., 2019). The proper combination of training stimuli and recovery periods produces physiological adaptations and increases sports performance (Clemente-Suarez et al., 2019). Athletes use numerous methods and tools, such as nutrition and ergogenic aids, compression garments, massage, or cryotherapy (Barnett, 2006) in order to optimize the recovery phase, looking for performance improvement. However, sleep is the most important method for recovery from daily load (Myllymaki et al., 2011). Previous studies (Vitale et al., 2017) focused on the relationship between exercise and sleep, suggesting that some factors affect sleep quality and recovery, such as the chronotype of the athlete or the load or time of the day of exercise practice. In our studies (2, 3, and 4), although players accumulated, as a group, adequate sleep (≥ 7h), a decreased duration of sleep was observed following night-training sessions (9 p.m.; studies 2 and 3) or an evening match (7 p.m.; study 4). In fact, an important finding was the consistent reduction in TST and a delay in sleep onset time following night-training sessions compared to rest days (Studies 2 and 3). Juliff et al. (2015) showed that sleep indices were likely dependent on the scheduling of practices of the particular sport. Furthermore, Vitale et al. (2019) showed that sleep duration and quality were lower during the night immediately following a night-match compared to previous or subsequent nights, in both female and male athletes. In our study with elite female soccer players (study 4), as a group, players accumulated adequate sleep duration and presented good sleep quality on all training-days and match days of the tournament. However, significantly decreased durations of TST and SE were observed after evening matches compared with day matches of the tournament. In fact, the impact of night matches (i.e., schedule time) on subsequent sleep is well established (Fullagar et al., 2016b; Sargent & Roach,

2016). For example, Sargent and Roach (2016) examined the sleep of elite Australian football players on the night immediately following a day match or following an evening match. During the night immediately after the evening match, the players initiated sleep 2.5 hours later and obtained 2.1 hours less sleep when compared to sleep immediately following the day match. In the present study, following evening matches, female soccer players initiated sleep much later compared to day matches, and obtained less sleep duration compared to day matches. Our results suggest that late evening exercise (Studies 2, 3, and 4), occurring close to bedtime sleep, could impose a high risk of obstructing falling asleep at night. Thus, an acceptable explanation for the results observed could be the time scheduling of the training and matches. This may suggest the potential value of sleep education strategies and interventions to promote appropriate sleep and recovery, especially after night competitions. This could be very relevant, since athletes are often unable to achieve recommended TST and SE, with lower values on the night of competitions compared with the previous night (Roberts et al., 2019). Of note, there is a sleep hygiene recommendation that suggests not performing intensive exercise within the last 3 h before bedtime (Myllymaki et al., 2011); however, this recommendation has not been adequately experimentally tested, and several studies (Hauri, 1968; O'Connor et al., 1998; Youngstedt et al., 1999) are not in accordance with this affirmation. This is specifically interesting, since most Portuguese women's soccer teams from the 1st and 2nd divisions habitually train at very late hours (9 p.m.), close to bedtime sleep, due to their daily life commitments (e.g., job, university) which need to be aligned with training schedules.

Accordingly, reduced sleep following different match-play scenarios (i.e., matches played away or at home) is also of concern for practitioners, given the potential for compromised recovery (Skein et al., 2013). For instance, due to the time needed to travel, sleep patterns after away-matches could be more affected than after home-matches (Fowler et al., 2015). In fact, changing match contexts can disrupt "normal" sleeping patterns of players (i.e., change of location, kick-off time, and travel (Fullagar et al., 2016a)). In one longitudinal study of this thesis (Study 3), female athletes presented delayed sleep onset time (+ 36 min) and

increased sleep latency (+ 5 min) following away-matches compared to home-matches. A possible explanation for these findings might be that players arrived home later after away-matches. Additionally, it could be speculated that post-match social activities (Nedelec et al., 2015a) had a greater influence after away-matches than home-matches since players travelled back home together. Long and international air travel could increase jet-lag symptoms and impair mood state (Bonnar et al., 2018), and subsequently affect sleep (Nedelec et al., 2015a) and HRV (Egan-Shuttler et al., 2018) indices in trained athletes. However, these issues seem not to be solely related to travel distance *per se* (Carriço et al., 2017) as the players in the current study did not have to travel by bus for more than 3 hours after away-matches.

Recent studies investigating the differences in sleep behaviours among soccer players have identified several potential chronic and acute causes of sleep disturbance (Vitale et al., 2017). One possible explanation for the findings observed when comparing night exercise with day exercise and rest days could be the athlete's exposure to stadia bright light. Light exposure may have an impact on sleep by extending sleep onset, reducing TST, and augmenting latency (Nedelec et al., 2015a). Our studies (Studies 2 and 3) showed that athletes were exposed to, approximately, > 1200 lux during night-training sessions. Factors such as luminance levels, exposure duration, and timing and wavelength of light have an important influence on the alerting response of humans, with bright polychromatic light (≥ 1000 lux) being sufficient to elicit maximal alerting effects (Cajochen, 2007).

Another possible explanation for the findings of the present thesis, i.e. increased and significant differences found in HR when comparing night-training sessions and official day matches with rest days (Studies 1, 2 and 3) could be the complexity of physiological changes acutely induced by exercise (e.g., increase in thermogenic hormones and elevation of body temperature and HR (Borsheim & Bahr, 2003)). Moreover, an effect of exercise on sleep disturbance may be related to the delay in reactivation of parasympathetic activity following exercise, leading to persistently high HR at bedtime, lasting for the first 3 (Study 1) or more sleeping hours (Studies 2 and 3). Previous studies concerning this

topic have reported elevated HR during sleep after strenuous (Hauri, 1968) and prolonged submaximal exercise (Mischler et al., 2003).

Despite overnight HR disturbances, no significant nocturnal HRV changes were noticed during the night-training days compared with the non-training days (i.e., rest days) in semi-professional female soccer players (Studies 1 and 2) and during 9 consecutive days of an international tournament in elite female soccer players (Study 4). These findings may indicate that the used HRV-derived methods (i.e. “hour by hour” and/or SWSE) were not sensitive enough to detect the overnight cardiac autonomic activity disturbances, in these specific observational studies, in (elite) female soccer players. However, as the implementation of both methods resulted in highly reliable lnRMSSD measures (Study 1), it can be put forth that overnight HRV could be sensitive (i.e., high-internal responsiveness) to positive and negative changes due to training sessions and matches. Alternatively, and more likely, it could also be suggested that the amount of training load prescribed to the investigated semi-professional soccer team (Studies 1 and 2) was not high enough to cause meaningful changes in the cardiac sympathetic and parasympathetic activities. Notably, in both referred studies (Studies 1 and 2), daily TRIMP ranging between ~73 and ~138 AU and s-RPE between ~193 and ~442 AU, respectively, was not high enough to cause overnight changes in the sympathetic and parasympathetic systems.

In a study conducted by Impellizzeri et al. (2004) involving 19 young male soccer players, the mean s-RPE during soccer-specific sessions ranged between 343 and 634 AU. Moreover, Milanez et al. (2014) reported that professional female futsal players accumulated between 343 and 419 AU (s-RPE). However, in that study, it was possible to observe (in a subsample) increased stress symptoms (i.e., reduced salivary immunoglobulin A concentrations and increased number of “worse than normal” responses to the Daily Analysis of Life Demands for Athletes questionnaire) when the s-RPE passed ~500 AU per day. Therefore, it can be hypothesized that high levels of training load (e.g., s-RPE > 600 AU), which is typical during soccer matches in male and female soccer players (Alexiou & Coutts, 2008; Impellizzeri et al., 2004), can substantially disturb overnight HRV. Additionally, in the second study of this thesis (Study 2), night-

training sessions associated with the lowest and highest TRIMP (Figure 2) did not result in different vagally-mediated HRV throughout the sleep hours. The current findings extend the previous results (Study 1) by showing that TRIMP ranging between ~78 and ~111 AU in night soccer training sessions does not affect overnight HRV compared to rest days. Nevertheless, this topic deserves future studies. For the moment, in highly trained female soccer players, training load in the range observed herein seems to not induce significant changes in HRV during post-exercise night sleep. Supporting this notion, the perceived well-being (as established by Hooper et al. (1995)) of the players from both studies (Studies 1 and 2) did not significantly change across the training days, thus indicating that the training load of the investigated studies was well tolerated by the players.

In addition, no significant changes in nocturnal HRV were noticed across 9 days of an international tournament (independently of being day training, day match, or evening match) in elite female soccer players (Study 4). Regarding the training and match loads of the investigated female soccer team, it appears that the s-RPE of training sessions and matches during the international tournament were not high enough to cause overnight changes in the cardiac autonomic system in this specific National team. Our study showed that, as a group, elite female soccer players can tolerate up to ~3000 AU across 9 days or ~600 AU per day of s-RPE during an international tournament, without presenting signs of severe nocturnal cardiac autonomic perturbation. In addition, training and match load parameters were not significantly correlated with HRV, indicating the absence of a dose-response feature in this sample of elite players that could suggest decreased tolerance to the higher loads experienced during the period of observation. It is probable these players are more resilient to sustained high levels of training and match load without presenting signs of severe nocturnal cardiac autonomic perturbation when compared to our studies conducted with semi-professional players (Studies 1 and 2). However, this needs to be further investigated. Furthermore, in Study 4, players seemed to display lower perturbation of nocturnal cardiac autonomic activity, as expressed by the lnRMSSD CV (Flatt et al., 2017a). Although the study comprised only 9 days of

observation, it can be globally inferred that players were coping well with the training sessions and matches. In fact, a reduced lnRMSSD CV without a clear decrease in the lnRMSSD, which occurred for most of these female soccer players, may reflect the possibility of a high level of readiness to perform (Esco et al., 2014) during the international tournament. This finding corroborates previous studies assessing HRV in athletes during the day (Flatt et al., 2017c; Nakamura et al., 2016).

Interestingly, in the third study (Study 3) the training load imposed on the semi-professional female soccer players appeared to be enough to cause a significant impact on HRV during SWSE. In fact, soccer practices significantly decreased RMSSD and HF (Camm et al., 1996). Moreover, the training loads measured in the night-training day and match day in the referred study were higher (e.g. TRIMP ~193 AU for night-training sessions and ~302 AU for day matches) compared to values detected in other studies (Studies 1 and 2), in which the cardiac autonomic homeostasis of female soccer players was not disturbed by night-training sessions with daily TRIMP ranging between ~73 and ~138 AU. Thus, it could be speculated that the training loads of training sessions and matches imposed on the players in the Study 3 were high enough to promote significant changes in vagal activity, expressed through the increase in HR during sleep. However, this topic deserves future investigations to better elucidate the relationship between training and/or match load and cardiac autonomic disturbance during sleep. Nevertheless, it is suggested that training and match loads in the ranges observed herein may induce significant changes in HRV during post-exercise night sleep in high-level female soccer players.

Nevertheless, and considering the nature of this thesis was observational/descriptive, we recognize as important limitations to mention here on discussion section the lack of control of other variables that could also explain sleep patterns and HRV results: such as the habitual training time-of-day of the athletes and chronotype, as already mentioned on literature review (see section *1.4.1. Autonomic cardiac function and sleep patterns in soccer*), hormonal information (e.g., menstrual cycle) and food intake before bedtime.

For instance, Julian et al. (2017) investigated the potential effects of menstrual cycle phase on performance in soccer specific tests (Yo-Yo Intermittent endurance test, counter movement jump and 3 x 30 m sprints). The authors found a reduction in maximal endurance performance during the mid-luteal phase of the menstrual cycle. However, the same effect was not observed for jumping and sprint performance. Therefore, consideration of cycle phase when monitoring a player's endurance capacity may be worthwhile.

Concerning food intake before bedtime, studies have suggested that particular foods/diets are important for re-entrainment of the peripheral circadian clock (Nedelec et al., 2015b). For example, a meal high in carbohydrate, but low in protein may theoretically facilitate uptake of tryptophan and its conversion to serotonin, inducing drowsiness and sleep; on the other hand, a meal high in protein but low in carbohydrate might enhance tyrosine uptake and conversion to epinephrine, increasing arousal levels (Leatherwood & Dragoo, 2013). Studies investigating the effects of carbohydrate ingestion on indices of sleep duration and quality are limited and provide contradictory results (Halson, 2014b). However, to counteract the potential decreased rate of muscle glycogen resynthesis among soccer players exposed to sleep deprivation (Skein et al., 2011), a preventive strategy may be to ensure additional carbohydrate is consumed in these circumstances (Burke et al., 2006). Furthermore, according to Ranchordas et al. (2017), it is important to ensure that recovery strategies are implemented every hour until sleep, encouraging more liquid based nutrient sources (e.g. milkshakes, sport supplement drink) to offset any potential gastrointestinal issues associated with the ingestion of solid foods before bedtime in soccer players. No caffeinated drinks (e.g. coffee, cola) should be consumed pre-sleep, but a snack containing casein (slow release protein) can be adopted before bedtime (Ranchordas et al., 2017).

Unfortunately, due to time and technical constraints, information about these variables, i.e. menstrual cycle and food intake before bedtime, was not collected. Therefore, the mechanisms underlying sleep and HRV results observed after exercise can only be speculated.

5.2. Individual approach: recovery status and training and match load monitoring in female soccer players

Everyday life experience overwhelmingly confirms that the magnitude of response to regular exercise training differs within individuals. This intra-individual variability of training efficacy is reflected in the concepts of talent or trainability and translates to “subject-by-training interaction” in statistical terms (Arbab-Zadeh et al., 2014; Chrzanowski-Smith et al., 2019). Moreover, this phenomenon is not only observed with regard to physical performance but also to virtually every physiological and health-related outcome measure (Bouchard & Rankinen, 2001).

As already mentioned in chapter I, the majority of research available examining the sleep of athletes, especially females, has typically averaged data across several nights, providing a mean estimate of usual sleep (Costa et al., 2018a; Costa et al., 2018b; Costa et al., 2018c; Lastella et al., 2015; Sargent et al., 2014b).

In our studies, when analyzing the data as a group, players accumulated adequate sleep duration (Watson et al., 2015) and presented good sleep quality (Ohayon et al., 2017) after night-training sessions and/or day matches (Studies 2 and 3). Additionally, in study 4, when analysed as a group, players accumulated adequate sleep duration and quality on all training days and day matches of the tournament. However, when we looked more carefully at the results of our studies (Studies 2 and 3), more specifically at the variability of sleep duration, we found that some female soccer players slept less than recommended after night-training sessions. The same situation occurs in our study conducted in elite female soccer players (Study 4), where individual sleep analysis showed that some players slept less than recommended during the tournament, especially after the evening match. Furthermore, another interesting and notable finding of the mentioned study (Study 4), was that six players (including one player who played all matches; player 10) seemed to constantly “compensate” the low sleep duration after participating in matches (independently of being day matches or evening

match), by extending sleep duration on the next day, probably as a “self-sleep hygiene” strategy.

In the same line, overnight changes in the cardiac autonomic system may present different results depending on the type of analysis performed (individual or as group), with high responders and low responders often getting lost in averaged data reports (Mann et al., 2014). The lnRMSSD CV has been assessed in studies involving highly-trained athletes as a marker of variation in daily assessed lnRMSSD (Esco et al., 2014). In a recent study (Flatt et al., 2017b), the authors suggested that a high diurnal lnRMSSD CV (subject 3 CV=14 % and subject 8 CV=12 %) was positively associated with perceived fatigue and negatively associated with the physical fitness of female soccer players. Moreover, another study found that diurnal lnRMSSD CV measured in swimmers can increase to values > 10 % during overload periods (Flatt et al., 2017c). In our study 4, as a group, lnRMSSD derived from the SWSE method displayed low average CV (6 %). In fact, most of the lnRMSSD values across all days of the tournament were located within the smallest worthwhile change range (3 %) (Buchheit, 2014). However, individually, two players (player 6 and 7) presented higher lnRMSSD CV (11.5 and 11.7 %; respectively) and a reduced average lnRMSSD (3.66 ms and 2.73 ms; respectively), contrasting with the remaining players of the team. Thus, overnight HRV during the observed international tournament was more susceptible to variations in these two players. Furthermore, it could be speculated that higher lnRMSSD CV associated with reduced average lnRMSSD during training and matches may be interpreted as a sign of overload (Flatt et al., 2017b). Therefore, although no significant within-participant correlation between lnRMSSD and training and match load could be detected in the current study, it is highly advisable that coaches closely examine individual cases of players that may be suffering some detrimental effects during the competition, in order to promote their recovery through sleep hygiene and other means (Simpson et al., 2017).

The importance of monitoring recovery status in athletes is well known and, consequently, monitoring and understanding individual training load is vital to promote physical performance increase and reduce injury risk.

Mismanagement of training load in team sports increases the risk of overreaching/injury when it is too high and originates loss of performance or detraining when it is too low. This is the main reason for finely monitoring internal training load using valid and reliable methods on an individual basis which can inform training prescription. The use of unobtrusive and cost-effective RPE scales across training and competition settings - compared with microtechnology sensors such as HR monitors - has been spreading in team sports. Therefore, it has become common practice to validate s-RPE as a measure of internal training load by testing its correlation with TRIMP and measures of external load (McLaren et al., 2018). The findings of study 5 indicate that s-RPE is acceptably valid for players of a highly-trained soccer squad, but also underline that measurement of HR can provide an additional objective evaluation of internal load (Impellizzeri et al., 2004; Scott & Lovell, 2018) as both metrics share ~61 % of the variance. More importantly, different discrete values of RPE from the CR-10 scale were associated with significantly different HR values, where a rise of one point on the scale can represent a meaningful change in the objectively determined exercise intensity. With this knowledge, coaches might estimate the cardiovascular demands of a given soccer training session using the RPE scale, which is a cost-free tool. However, further studies must determine whether these values can be generalized to other samples of female athletes. Furthermore, it is needed to extend our findings in the range of RPE values > 5, since we only included training sessions with RPE varying between 2 and 5. In this sense, other training modes (e.g., high-intensity interval training, repeated sprints training, extensive technical drills, etc.) should be included in the observations. Finally, although there was great intra- and inter-player response variability, this study found that female soccer players spent adequate time > 90 % of HR_{peak} (Castagna et al., 2013) during training sessions. On average, players spent ~8 % of training time at HR > 90 % of HR_{peak} (resulting in ~7 min per session). This is within the recommendations to improve aerobic fitness (Castagna et al., 2013) referring that, achieving 7–8 % of training time at HR > 90 % of HR_{peak}, players can significantly increase aerobic fitness (lactate threshold and oxygen uptake). These results suggest that technical staff should be encouraged to monitor HR

during training sessions to better adjust training loads and strategies to adequately stimulate the cardiorespiratory system of all players. A good strategy could be prescribing high-intensity interval training using standard field tests to elicit known cardiovascular responses (i.e., > 90 % of HR_{peak}) (Buchheit, 2008; Impellizzeri et al., 2006) to those players accumulating a short time period > 90 % of HR_{peak} during technical training.

In summary, for understanding the athlete's individual responses and to optimize the scheduling of training and recovery strategies it is crucial a comprehensive monitoring of his/her performance, fitness and fatigue status. Moreover, an "individual approach" in athletes monitoring, could help in better prescribe training contents and more adequately manage fatigue, as well as recommend pertinent post-match recovery strategies, such as sleep hygiene interventions.

6. Limitations

Given applied research nature of this thesis several limitations can be pointed out:

- Polysomnographic measurements (typically includes an assessment of eye movement, brain activity, HR, muscle activity, oxygen saturation, breathing rate and body movement) were not used in the present thesis, and therefore the impact of training and match load performed at different times of the day and in different locations, as well as during an international tournament, on sleep stages cannot be discussed;
- Usually some questionnaires (e.g. diaries) and specific scales for sleep investigation are used with actigraphy, with the intention of complementing the information extracted from the actogram, especially when practitioners intend to record napping times during the day. Unfortunately, technical problems and/or player compliance resulted in several missing data points, and for this reason we decided to remove this information from the studies;

- Although players had a period of familiarization with the devices used to avoid training and match activities or sleep pattern being disturbed by the equipment, some players reported some discomfort during the data collection. Unfortunately, this type of constraints associated with data collection with HR monitors and watches could not be avoided;
- Despite having a relatively standardized ideal sleep amount of time (i.e., ~7–9 h/day) for most of the population, many individuals have different needs for hours of sleep per night (Grandner & Kripke, 2004). Individuals are classified according to their duration of sleep as short or long sleepers (Aeschbach et al., 1996; Aeschbach et al., 2003). Short sleepers may present good sleep quality perception and recovery status with a few hours of sleep, while long sleepers need nine or more hours of sleep to feel recovered or rested. However, this characterization was not performed, which is recognized as an important limitation of the current thesis;
- Given Study 4 was conducted in a field setting (i.e., real-world scenario), there were many uncontrolled factors that may have affected the athletes' sleep, other than match and or training scheduling and load (e.g., use of caffeine; social media after lights out, electronic devices, level of light exposure during daytime, twin rooms, temperature in rooms, and perceived stress/well-being). In fact, additional measures (e.g., well-being ratings) are needed to contextualize and better interpret changes in HRV (Bellenger et al., 2016; Flatt et al., 2017b). Unfortunately, due to time and technical constraints, well-being, fitness level, and information about perceived stress was not collected, and we recognize this as an important limitation of the current study to better understand the HRV values of each player during the tournament;
- In Study 4, since there were missing data on some days, caution should be taken when interpreting the CV values for sleep and HRV. Furthermore, this study was limited by the fact that a "real baseline" was not assessed for possible sleep and nocturnal HRV comparisons across the 9 days of the tournament. Finally, while the s-RPE method may be simple, valid, and reliable, in this study we did not use other types of internal training and match

load monitoring (e.g., HR monitors), which could provide objective information for interpretation of the physiological responses of players;

- In Study 5, an eventual effect of residual fatigue (especially on the first training session of the week) caused by playing the weekly match was not controlled. This is important since in this study players had dissimilar participation times (from 0 to 90 min) and this aspect could influence s-RPE and TRIMP (Rodriguez-Marroyo et al., 2012);
- Finally, we emphasize that since individual characteristics (e.g., aerobic fitness) can influence the relationship between RPE and HR, our results cannot be generalized to other samples of soccer players.

7. Conclusions

Based on the conclusions of each of the studies included in this dissertation, the following major conclusions can be outlined:

- Late-night soccer training does not seem to affect SWSE or “hour-by-hour” HRV indices in highly trained female soccer players, but elevates HR during the first 3 sleeping hours compared with the non-training days, throughout a 1 week competitive in-season microcycle.

- The implementation of SWSE and “hour-by-hour” methods resulted in highly reliable lnRMSSD measures, suggesting that both methods could be used to record overnight HRV in high-level female soccer players.

- Exercise training conducted at night (after 9 p.m.) may disturb sleep and increase HR, whereas limited effects can be expected in overnight HRV of high-level female soccer players, during 3 consecutive weeks of the competitive in-season.

- The time of day for soccer practice and match location may cause disruption in sleep patterns. Additionally, night-training and match days, compared to

rest days, may affect nocturnal autonomic cardiac activity of high-level female soccer players during 6 weeks of the competitive season.

- High-level female soccer players engaged in soccer training late in the night throughout 3 and/or 6 consecutive weeks of the competitive season, displayed an average of ≥ 7 hours of sleep per night. Given that 7 to 9 hours of sleep per night might be required to avoid cumulative deficits in daytime function, it is reasonable to suggest that recovery was not impaired.

- During 9 days of an international tournament, some elite female soccer players presented less sleep than recommended in some days of the tournament. However, the highest number of athletes sleeping less than 7 hours was found after evening matches compared with the remaining days. Nevertheless, all players displayed good sleep quality for each day of the tournament. Additionally, most players seemed to present small fluctuations in nocturnal cardiac autonomic activity.

- Overall, elite female soccer players from a National team seemed to be highly resilient to training and match loads during an international tournament. Moreover, this study highlighted the substantial individual variability in sleep and HRV measures, suggesting the adoption of an individual approach to monitor sleep, training and match loads, and recovery, to better understand how players cope with highly demanding competitions.

- We confirmed the convergent validity of s-RPE and TRIMP and different % HR_{peak} values observed for each discrete RPE using within-subjects statistical approach.

- Finally, during technical training sessions, soccer players presented very high variability in the time spent > 90 % of HR_{peak}, although on average they tended to reach adequate exercise intensity to improve or maintain their aerobic fitness.

8. Practical applications

The primary purpose of this thesis was to expand the current scientific knowledge in female soccer, especially in areas related to autonomic cardiac function and sleep patterns in different match and training scenarios. The following practical applications should be considered by practitioners in the field:

- The participants of studies 1, 2, 3 and 5 were mainly female collegiate athletes who need to balance sports, academic study, and their daily life. Previous studies have not focused on this kind of population, which needs special consideration. Tracking sleep and recovery metrics over the course of a competitive season may assist coaches and sports scientists in making informed decisions regarding training and recovery in female collegiate athletes.
- Recent studies have reported ANS status to be an important factor governing training response. This is because assessment of ANS function effectively includes important information concerning acute and chronic physiological processes that occur before, during, and after exercise training. Our results confirm that nocturnal HRV monitoring can be used as a simple non-invasive tool to evaluate, at an individual level, the impact of training and match load performed at different times of the day and in different locations, as well as during international tournaments. This information might be of interest to practitioner's intent on monitoring the response to specific training prescriptions.
- Recovery status measurements (i.e., sleep patterns and nocturnal HRV) can also be collected on rest days in case of injury or illness and can further be used to modify individual training and recovery plans before the first daily session.
- During congested competitive periods, soccer players follow strict match and training schedules that can reduce sleep duration, impairing the recovery process, especially when training sessions and/or matches are performed close to bedtime sleep. This fact is relevant, since according to our studies, in

Portugal female soccer players habitually train at very late hours (9 p.m.), close to bedtime sleep, due to their daily life commitments (e.g., job, university) which need to be aligned with training schedules. Thus, it is suggested that athletes and coaches organize the training program not only according to match schedules, but also aiming to improve sleep routines for optimal recovery.

- Together, actigraphic variables and HRV indices provide more complete information on sleep patterns and cardiac autonomic function that elucidates about athlete recovery state. Moreover, both indices can be used to improve the quality of monitoring training and match load, are easily assessed at the training and/or match facilities and at the athletes' own homes, and can be implemented in a team's daily routine, in a real-world scenario.
- The substantial individual variability in sleep and HRV suggests the adoption of an individual approach to sleep (e.g., sleep hygiene), load monitoring, and recovery interventions in team sports. In fact, the competition scenario of successive matches often results in squad rotation between matches. However, some players will often be required to play in multiple matches. In these scenarios, individualised recovery and monitoring techniques may be required to ensure that all players are in peak condition for each match.
- The s-RPE method has been proven to be a simple and effective way to quantify the internal training load. In fact, there is a high association between s-RPE and HR-based TRIMP, supporting the use of the former when HR devices are not available to the team.
- Even in the absence of HR recordings, our results provide coaches with specific ranges of % HR_{peak} expected to be reached in each RPE category from 2–5 (in players with similar characteristics to ours), encompassing easy to hard training sessions for female soccer players.
- Monitoring the amount of high-intensity work in the time spent above 90 % of HR_{peak} could be important for coaches and technical staff to better adjust training load (i.e., adapt and manipulate exercises) and adequately stimulate cardiorespiratory adaptations of all players.

- Together, perceptual and objective (HR) methods provide more complete information for quantifying internal training load of athletes and can be used to improve the quality of training load monitoring.

9. Future research

The findings of the current thesis have also highlighted several considerations for future research:

- Sleep patterns and (nocturnal) HRV should be examined in combination rather than isolation, especially when training sessions and matches are close to bedtime. Even though sleep has been shown to be influenced by athlete training status, the association with resting (i.e., nocturnal) HR and HRV remains unclear in female soccer players. Moreover, it is suggested to investigate the association (e.g. correlations) between recovery status variables (i.e., sleep pattern and nocturnal HRV) with internal and external load, to better understand fatigue and recovery in (female) soccer players.
- Most athletes that participated in the studies included in this thesis were collegiate athletes (Studies 1, 2, 3, and 5). Improving sleep in collegiate athletes has significant implications for health, athletic performance, and academic achievement. However, athletes frequently fail to obtain restorative sleep. Factors related to their academic pursuits, training, and competition can alter sleep patterns. Therefore, topics such as: 1) sleep patterns and disorders among collegiate athletes; 2) sleep and optimal functioning among athletes; 3) screening, tracking, and assessment of athletes' sleep; and 4) interventions (i.e. sleep hygiene) to improve sleep, must be further investigated.
- Future research with female athletes should examine the sleep patterns and (nocturnal) HRV in combination with other variables (e.g., menstrual cycle). This will strengthen the approach, by identifying sleep and HRV disturbing factors in overloading periods.

- Given the relationship between exercise duration and the corresponding load, analysis of sleep patterns and HRV responses relative to playing time should be performed in future studies.
- All studies from this thesis were observational/descriptive. Therefore, it could be important that future research examined different sleep hygiene interventions (e.g., napping) in combination with performance variables in (elite) female soccer players, especially when training sessions and matches are close to bedtime sleep.
- Integration of tactical and technical metrics with recovery status data appears important to identify changes in performance in soccer. As sport scientists, we may tend to focus on the physical and physiological aspects of sport, however, true soccer performance needs to be considered as a construct. A coach may be interested in the change in technical or tactical aspects which, in their view, may have a greater impact on match outcome than physical and physiological components.
- Due to the initial purposes of study 5, the necessity to extend our findings in the range of RPE values > 5 in this and other populations of athletes is needed (since we only included training sessions with RPEs varying between 2 and 5). In this sense, other training modes (e.g., high-intensity interval training, repeated sprints training, extensive technical drills, etc.) need to be included in the observations. Moreover, we selected a period in which training sessions were relatively homogeneous in terms of intensity and duration, so training contents eliciting greater cardiorespiratory and perceptual demands (e.g., different SSG formats [1 vs. 1]) should be included in future research.

References

References

Abel, T., Havekes, R., Saletin, J. M., & Walker, M. P. (2013). Sleep, plasticity and memory from molecules to whole-brain networks. *Current Biology, 23*(17), R774-788.

Achten, J., & Jeukendrup, A. E. (2003). Heart rate monitoring: Applications and limitations. *Sports Medicine, 33*(7), 517-538.

Aeschbach, D., Cajochen, C., Landolt, H., & Borbely, A. A. (1996). Homeostatic sleep regulation in habitual short sleepers and long sleepers. *American Journal of Physiology, 270*(1 Pt 2), R41-53.

Aeschbach, D., Sher, L., Postolache, T. T., Matthews, J. R., Jackson, M. A., & Wehr, T. A. (2003). A longer biological night in long sleepers than in short sleepers. *The Journal of Clinical Endocrinology & Metabolism, 88*(1), 26-30.

Al Haddad, H., Laursen, P. B., Ahmaidi, S., & Buchheit, M. (2009). Nocturnal heart rate variability following supramaximal intermittent exercise. *International Journal of Sports Physiology and Performance, 4*(4), 435-447.

Alexiou, H., & Coutts, A. J. (2008). A comparison of methods used for quantifying internal training load in women soccer players. *International Journal of Sports Physiology and Performance, 3*(3), 320-330.

Allada, R., & Siegel, J. M. (2008). Unearthing the phylogenetic roots of sleep. *Current Biology 18*(15), R670-R679.

Ancoli-Israel, S., Cole, R., Alessi, C., Chambers, M., Moorcroft, W., & Pollak, C. P. (2003). The role of actigraphy in the study of sleep and circadian rhythms. *Sleep, 26*(3), 342-392.

Andersson, H. (2010). *The physiological impact of soccer on elite female players and the effects of active recovery training*. Örebro: Helena Andersson. Doctoral Thesis presented to Örebro University.

Andersson, H., Karlsen, A., Blomhoff, R., Raastad, T., & Kadi, F. (2010a). Plasma antioxidant responses and oxidative stress following a soccer game in elite

female players. *Scandinavian Journal of Medicine & Science in Sports, 20*(4), 600-608.

Andersson, H., Randers, M., Heiner-Møller, A., Krustrup, P., & Mohr, M. (2010b). 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), 912-919.

Arbab-Zadeh, A., Perhonen, M., Howden, E., Peshock, R. M., Zhang, R., Adams-Huet, B., Haykowsky, M. J., & Levine, B. D. (2014). Cardiac remodeling in response to 1 year of intensive endurance training. *Circulation, 130*(24), 2152-2161.

Atkinson, G., Batterham, A. M., Jones, H., Taylor, C. E., Willie, C. K., & Tzeng, Y. C. (2011). Appropriate within-subjects statistical models for the analysis of baroreflex sensitivity. *Clinical Physiology and Functional Imaging, 31*(1), 80-82.

Aubert, A. E., Seps, B., & Beckers, F. (2003). Heart rate variability in athletes. *Sports Medicine, 33*(12), 889-919.

Baker, F. C., Maloney, S., & Driver, H. S. (1999). A comparison of subjective estimates of sleep with objective polysomnographic data in healthy men and women. *Journal of Psychosomatic Research., 47*(4), 335-341.

Bangsbo, J. (1994). The physiology of soccer: With special reference to intense intermittent exercise. *Acta Physiologica Scandinavica, 619*, 1-155.

Bangsbo, J., Mohr, M., & Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal Sports Science 24*, 665-674.

Banister, E. W., & Hamilton, C. L. (1985). Variations in iron status with fatigue modelled from training in female distance runners. *European Journal of Applied Physiology and Occupational Physiology, 54*(1), 16-23.

Banks, S., & Dinges, D. F. (2007). Behavioral and physiological consequences of sleep restriction. *Journal of Clinical of Sleep Medicine 3*(5), 519-528.

Barnett, A. (2006). Using recovery modalities between training sessions in elite athletes: does it help? *Sports Medicine, 36*(9), 781-796.

Beersma, D. G., & Gordijn, M. C. (2007). Circadian control of the sleep-wake cycle. *Physiology & Behavior, 90*(2-3), 190-195.

Bei, B., Wiley, J. F., Trinder, J., & Manber, R. (2016). Beyond the mean: A systematic review on the correlates of daily intraindividual variability of sleep/wake patterns. *Sleep Medicine Reviews, 28*, 108-124.

Bellenger, C. R., Karavirta, L., Thomson, R. L., Robertson, E. Y., Davison, K., & Buckley, J. D. (2016). Contextualizing parasympathetic hyperactivity in functionally overreached athletes with perceptions of training tolerance. *International Journal of Sports Physiology and Performance, 11*(7), 685-692.

Bendiksen, M., Pettersen, S. A., Ingebrigtsen, J., Randers, M. B., Brito, J., Mohr, M., Bangsbo, J., & Krustrup, P. (2013). Application of the Copenhagen Soccer Test in high-level women players: Locomotor activities, physiological response and sprint performance. *Human Movement Science, 32*(6), 1430-1442.

Beneke, R., Leithauser, R. M., & Ochentel, O. (2011). Blood lactate diagnostics in exercise testing and training. *International Journal of Sports Physiology and Performance, 6*(1), 8-24.

Besedovsky, L., Lange, T., & Born, J. (2012). Sleep and immune function. *Pflügers Archiv: European Journal of Physiology, 463*(1), 121-137.

Bilchick, K. C., & Berger, R. D. (2006). Heart rate variability. *Journal of Cardiovascular Electrophysiology, 17*(6), 691-694.

Billman, G. E. (2013). The LF/HF ratio does not accurately measure cardiac sympatho-vagal balance. *Frontiers in Physiology, 4*, 26.

Bishop, D. (2008). An applied research model for the sport sciences. *Sports Medicine, 38*(3), 253-263.

Bland, J. M., & Altman, D. G. (1995). Calculating correlation coefficients with repeated observations: Part 1: Correlation within subjects. *BMJ, 310*(6977), 446.

Bonato, M., Agnello, L., Galasso, L., Montaruli, A., Roveda, E., Merati, G., La Torre, A., & Vitale, J. A. (2017). Acute modification of cardiac autonomic function of high-intensity interval training in collegiate male soccer players

with different chronotype: A cross-over study. *Journal of Sports Science and Medicine, 16*(2), 286-294.

Bonnar, D., Bartel, K., Kakoschke, N., & Lang, C. (2018). Sleep interventions designed to improve athletic performance and recovery: A systematic review of current approaches. *Sports Medicine, 48*(3), 683-703.

Borresen, J., & Lambert, M. I. (2009). The quantification of training load, the training response and the effect on performance. *Sports Medicine, 39*(9), 779-795.

Borsheim, E., & Bahr, R. (2003). Effect of exercise intensity, duration and mode on post-exercise oxygen consumption. *Sports Medicine, 33*(14), 1037-1060.

Bosquet, L., Merkari, S., Arvisais, D., & Aubert, A. E. (2008). Is heart rate a convenient tool to monitor over-reaching? A systematic review of the literature. *British Journal of Sports Medicine, 42*(9), 709-714.

Bouchard, C., & Rankinen, T. (2001). Individual differences in response to regular physical activity. *Medicine & Science in Sports & Exercise, 33*(6 Suppl), S446-451.

Boullosa, D. A., Abreu, L., Nakamura, F. Y., Munoz, V. E., Dominguez, E., & Leicht, A. S. (2013). Cardiac autonomic adaptations in elite spanish soccer players during preseason. *International Journal of Sports Physiology and Performance, 8*(4), 400-409.

Bradley, P. S., Dellal, A., Mohr, M., Castellano, J., & Wilkie, A. (2014). Gender differences in match performance characteristics of soccer players competing in the UEFA Champions League. *Human Movement Science, 33*, 159-171.

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High-intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences, 27*(2), 159-168.

Brandenberger, G., Buchheit, M., Ehrhart, J., Simon, C., & Piquard, F. (2005). Is slow wave sleep an appropriate recording condition for heart rate variability analysis? *Autonomic Neuroscience, 121*(1-2), 81-86.

Bricout, V. A., Dechenaud, S., & Favre-Juvin, A. (2010). Analyses of heart rate variability in young soccer players: The effects of sport activity. *Autonomic Neuroscience, 154*(1-2), 112-116.

Brink, M. S., Nederhof, E., Visscher, C., Schmikli, S. L., & Lemmink, K. A. (2011). Monitoring load, recovery, and performance in young elite soccer players. *Journal of Strength and Conditioning Research, 24*(3), 597–603.

Brooks, A., & Lack, L. (2006). A brief afternoon nap following nocturnal sleep restriction: Which nap duration is most recuperative? *Sleep, 29*(6), 831-840.

Buchheit, M. (2008). The 30-15 intermittent fitness test: accuracy for individualizing interval training of young intermittent sport players. *Journal of Strength and Conditioning Research, 22*(2), 365-374.

Buchheit, M. (2014). Monitoring training status with HR measures: Do all roads lead to Rome? *Frontiers in Physiology, 5*, 73.

Buchheit, M., Chivot, A., Parouty, J., Mercier, D., Al Haddad, H., Laursen, P. B., & Ahmaidi, S. (2010). Monitoring endurance running performance using cardiac parasympathetic function. *European Journal of Applied Physiology, 108*(6), 1153-1167.

Buchheit, M., Millet, G. P., Parisy, A., Pourchez, S., Laursen, P. B., & Ahmaidi, S. (2008). Supramaximal training and postexercise parasympathetic reactivation in adolescents. *Medicine & Science in Sports & Exercise, 40*(2), 362-371.

Buchheit, M., Racinais, S., Bilsborough, J. C., Bourdon, P. C., Voss, S. C., Hocking, J., Cordy, J., Mendez-Villanueva, A., & Coutts, A. J. (2013). Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. *Journal of Science and Medicine in Sport, 16*(6), 550-555.

Buchheit, M., Simon, C., Piquard, F., Ehrhart, J., & Brandenberger, G. (2004). Effects of increased training load on vagal-related indexes of heart rate variability: A novel sleep approach. *American Journal of Physiology-Heart and Circulatory Physiology, 287*(6), H2813-2818.

Buchheit, M., Simpson, M. B., Al Haddad, H., Bourdon, P. C., & Mendez-Villanueva, A. (2012). Monitoring changes in physical performance with heart rate measures in young soccer players. *European Journal of Applied Physiology, 112*(2), 711-723.

Burke, L. M., Loucks, A. B., & Broad, N. (2006). Energy and carbohydrate for training and recovery. *Journal of Sports Sciences, 24*(7), 675-685.

Burton, A. R., Rahman, K., Kadota, Y., Lloyd, A., & Vollmer-Conna, U. (2010). Reduced heart rate variability predicts poor sleep quality in a case-control study of chronic fatigue syndrome. *Experimental Brain Research, 204*(1), 71-78.

Cajochen, C. (2007). Alerting effects of light. *Sleep Medicine Reviews, 11*(6), 453-464.

Camm, A. J., Malik, M., Bigger, J. T., Breithardt, G., Cerutti, S., Cohen, R. J., & et al. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *Circulation, 93*, 1043–1065.

Carriço, S., Skorski, S., Duffield, R., Mendes, B., Calvete, F., & Meyer, T. (2017). Post-match sleeping behavior based on match scheduling over a season in elite football players. *Science and Medicine in Football, 2*(1), 9-15.

Casamichana, D., Castellano, J., & Castagna, C. (2012). Comparing the physical demands of friendly matches and small-sided games in semiprofessional soccer players. *Journal of Strength and Conditional Research, 26*(3), 837-843.

Cassirame, J., Stuckey, M. I., Sheppard, F., & Tordi, N. (2013). Accuracy of the Minicardio system for heart rate variability analysis compared to ECG. *The Journal of Sports Medicine and Physical Fitness, 53*(3), 248-254.

Castagna, C., & Castellini, E. (2013). Vertical jump performance in italian male and female national team soccer players. *Journal of Strength and Conditioning Research, 27*(4), 1156-1161.

Castagna, C., Impellizzeri, F. M., Chaouachi, A., & Manzi, V. (2013). Preseason variations in aerobic fitness and performance in elite-standard soccer players: A team study. *Journal of Strength and Conditioning Research, 27*(11), 2959-2965.

Chennaoui, M., Arnal, P. J., Drogou, C., Sauvet, F., & Gomez-Merino, D. (2016). Sleep extension increases IGF-I concentrations before and during sleep deprivation in healthy young men. *Applied Physiology, Nutrition, and Metabolism, 41*(9), 963-970.

Chrzanowski-Smith, O. J., Piatrikova, E., Betts, J. A., Williams, S., & Gonzalez, J. T. (2019). Variability in exercise physiology: Can capturing intra-individual variation help better understand true inter-individual responses? *European Journal of Applied Physiology*, 1-17.

Clemente-Suarez, V. J., Delgado-Moreno, R., Gonzalez, B., Ortega, J., & Ramos-Campo, D. J. (2019). Amateur endurance triathletes' performance is improved independently of volume or intensity based training. *Physiology & Behavior, 205*, 2-8.

Costa, J. A., Brito, J., Nakamura, F. Y., Figueiredo, P., Oliveira, E., & Rebelo, A. (2018a). Sleep patterns and nocturnal cardiac autonomic activity in female athletes are affected by the timing of exercise and match location. *Chronobiology International, 36*(3), 360-373.

Costa, J. A., Brito, J., Nakamura, F. Y., Oliveira, E. M., Costa, O. P., & Rebelo, A. N. (2018b). Does night-training load affect sleep patterns and nocturnal cardiac autonomic activity in high-level female soccer players? *International Journal of Sports Physiology and Performance, 14*(6), 779-787.

Costa, J. A., Brito, J., Nakamura, F. Y., Oliveira, E. M., & Rebelo, A. N. (2018c). Effects of late-night training on "slow-wave sleep episode" and hour-by-hour-derived nocturnal cardiac autonomic activity in female soccer players. *International Journal of Sports Physiology and Performance, 13*(5), 638-644.

Crocker, A., & Sehgal, A. (2010). Genetic analysis of sleep. *Genes & Development, 24*(12), 1220-1235.

Czeisler, C. A., Allan, J. S., Strogatz, S. H., Ronda, J. M., Sanchez, R., Rios, C. D., Freitag, W. O., Richardson, G. S., & Kronauer, R. E. (1986). Bright light resets the human circadian pacemaker independent of the timing of the sleep-wake cycle. *Science, 233*(4764), 667-671.

Datson, N., Hulton, A., Andersson, H., Lewis, T., Weston, M., Drust, B., & Gregson, W. (2014). Applied physiology of female soccer: An update. *Sports Medicine, 44*(9), 1225-1240.

Davis, J. A., & Brewer, J. (1993). Applied physiology of female soccer players. *Sports Medicine, 16*(3), 180-189.

de Souza, L., Benedito-Silva, A. A., Pires, M. L., Poyares, D., Tufik, S., & Calil, H. M. (2003). Further validation of actigraphy for sleep studies. *Sleep, 26*(1), 81-85.

Di Salvo, V., Baron, R., Tschan, H., Calderon Montero, F. J., Bachl, N., & Pigozzi, F. (2007). Performance characteristics according to playing position in elite soccer. *International Journal of Sports Medicine, 28*(3), 222-227.

Drust, B., Waterhouse, J., Atkinson, G., Edwards, B., & Reilly, T. (2005). Circadian rhythms in sports performance: An update. *Chronobiology international, 22*(1), 21-44.

Dunican, I. C., Martin, D. T., Halson, S. L., Reale, R. J., Dawson, B. T., Caldwell, J. A., Jones, M. J., & Eastwood, P. R. (2017). The effects of the removal of electronic devices for 48 hours on sleep in elite judo athletes. *Journal of Strength and Conditioning Research, 31*(10), 2832-2839.

Dupont, G., Nedelec, M., McCall, A., McCormack, D., Berthoin, S., & Wisloff, U. (2010). Effect of 2 soccer matches in a week on physical performance and injury rate. *The American Journal of Sports Medicine, 38*(9), 1752-1758.

Egan-Shuttler, J. D., Edmonds, R., & Ives, S. J. (2018). The efficacy of heart rate variability in tracking travel and training stress in youth female rowers: A preliminary study. *Journal of Strength and Conditioning Research*.

Esco, M. R., Flatt, A. A., & Nakamura, F. Y. (2016). Initial weekly HRV response is related to the prospective change in vo2max in female soccer players. *International Journal of Sports Medicine, 37*(6), 436-441.

Esco, M. R., Snarr, R. L., Flatt, A., Leatherwood, M., & Whittaker, A. (2014). Tracking changes in maximal oxygen consumption with the heart rate index in female collegiate soccer players. *Journal of Human Kinetics, 42*, 103-111.

Fallon, K. E. (2007). Blood tests in tired elite athletes: expectations of athletes, coaches and sport science/sports medicine staff. *British Journal of Sports Medicine, 41*(1), 41-44.

Fazackerley, L. A., Fell, J. W., & Kitic, C. M. (2019). The effect of an ultra-endurance running race on heart rate variability. *European Journal of Applied Physiology, 119*(9), 2001-2009.

Ferreira, M., Jr., & Zanesco, A. (2016). Heart rate variability as important approach for assessment autonomic modulation. *Motriz: Revista de Educação Física, 22*(2), 3-8.

Fietze, I., Strauch, J., Holzhausen, M., Glos, M., Theobald, C., Lehnkering, H., & Penzel, T. (2009). Sleep quality in professional ballet dancers. *Chronobiology international, 26*(6), 1249-1262.

Flatt, A. A., & Esco, M. R. (2013). Validity of the ithlete Smart Phone Application for determining ultra-short-term heart rate variability. *Journal of Human Kinetics, 39*, 85-92.

Flatt, A. A., Esco, M. R., & Nakamura, F. Y. (2017a). Individual heart rate variability responses to preseason training in high level female soccer players. *Journal of Strength and Conditioning Research, 31*(2), 531-538.

Flatt, A. A., Esco, M. R., Nakamura, F. Y., & Plews, D. J. (2017b). Interpreting daily heart rate variability changes in collegiate female soccer players. *The Journal of Sports Medicine and Physical Fitness, 57*(6), 907-915.

Flatt, A. A., Hornikel, B., & Esco, M. R. (2017c). Heart rate variability and psychometric responses to overload and tapering in collegiate sprint-swimmers. *Journal of Science and Medicine in Sport, 20*(6), 606-610.

Foster, C. (1998). Monitoring training in athletes with reference to overtraining syndrome. *Medicine & Science in Sports & Exercise, 30*(7), 1164-1168.

Fowler, P., Duffield, R., & Vaile, J. (2015). Effects of simulated domestic and international air travel on sleep, performance, and recovery for team sports. *Scandinavian Journal of Medicine & Science in Sports, 25*(3), 441-451.

Frank, M. G., & Benington, J. H. (2006). The role of sleep in memory consolidation and brain plasticity: dream or reality? *Neuroscientist, 12*(6), 477-488.

Fullagar, H., Duffield, R., Skorski, S., Coutts, A. J., Julian, R., & Meyer, T. (2015a). Sleep and recovery in team sport: Current sleep-related issues facing professional team-sport athletes. *International Journal of Sports Physiology and Performance, 10*(8), 950-957.

Fullagar, H., Skorski, S., Duffield, R., Hammes, D., Coutts, A. J., & Meyer, T. (2015b). Sleep and athletic performance: The effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. *Sports Medicine, 45*(2), 161-186.

Fullagar, H., Skorski, S., Duffield, R., Julian, R., Bartlett, J., & Meyer, T. (2016a). Impaired sleep and recovery after night matches in elite football players. *Journal of Sports Sciences, 34*(14), 1333-1339.

Fullagar, H., Skorski, S., Duffield, R., & Meyer, T. (2016b). The effect of an acute sleep hygiene strategy following a late-night soccer match on recovery of players. *Chronobiology International, 33*(5), 490-505.

Gabbett, T. J., & Mulvey, M. J. (2008). Time-motion analysis of small-sided training games and competition in elite women soccer players. *Journal of Strength and Conditioning Research, 22*(2), 543-552.

Gamelin, F. X., Berthoin, S., & Bosquet, L. (2006). Validity of the polar S810 heart rate monitor to measure R-R intervals at rest. *Medicine & Science in Sports & Exercise, 38*(5), 887-893.

Garvican, L. A., Hammond, K., Varley, M. C., Gore, C. J., Billaut, F., & Aughey, R. J. (2014). Lower running performance and exacerbated fatigue in soccer played at 1600 m. *International Journal of Sports Physiology and Performance, 9*(3), 397-404.

Gaudino, P., Iaia, F. M., Strudwick, A. J., Hawkins, R. D., Alberti, G., Atkinson, G., & Gregson, W. (2015). Factors influencing perception of effort (session rating of perceived exertion) during elite soccer training. *International Journal of Sports Physiology and Performance, 10*(7), 860-864.

George, C. F., Kab, V., & Levy, A. M. (2003). Increased prevalence of sleep-disordered breathing among professional football players. *The New England Journal of Medicine, 348*(4), 367-368.

Goel, N., Rao, H., Durmer, J. S., & Dinges, D. F. (2009). Neurocognitive consequences of sleep deprivation. *Seminars in Neurology, 29*(4), 320-339.

Gogenur, I. (2010). Postoperative circadian disturbances. *Danish Medical Bulletin, 57*(12), B4205.

Gogenur, I., Bisgaard, T., Burgdorf, S., van Someren, E., & Rosenberg, J. (2009a). Disturbances in the circadian pattern of activity and sleep after laparoscopic versus open abdominal surgery. *Surgical Endoscopy, 23*(5), 1026-1031.

Gogenur, I., Kucukakin, B., Bisgaard, T., Kristiansen, V., Hjortso, N. C., Skene, D. J., & Rosenberg, J. (2009b). The effect of melatonin on sleep quality after laparoscopic cholecystectomy: a randomized, placebo-controlled trial. *Anesthesia and Analgesia, 108*(4), 1152-1156.

Gosselin, N., Lassonde, M., Petit, D., Leclerc, S., Mongrain, V., Collie, A., & Montplaisir, J. (2009). Sleep following sport-related concussions. *Sleep Medicine, 10*(1), 35-46.

Grandner, M. A., & Kripke, D. F. (2004). Self-reported sleep complaints with long and short sleep: A nationally representative sample. *Psychosomatic Medicine, 66*(2), 239-241.

Gravina, L., Ruiz, F., Lekue, J. A., Irazusta, J., & Gil, S. M. (2011). Metabolic impact of a soccer match on female players. *Journal of Sports Sciences, 29*(12), 1345-1352.

Gupta, L., Morgan, K., & Gilchrist, S. (2017). Does elite sport degrade sleep quality? A systematic review. *Sports Medicine, 47*(7), 1317-1333.

Halson, S. L. (2008). Nutrition, sleep and recovery. *European Journal of Sport Science, 8*(2), 119-126.

Halson, S. L. (2014a). Monitoring training load to understand fatigue in athletes. *Sports Medicine, 44*(Suppl 2), S139-147.

Halson, S. L. (2014b). Sleep in elite athletes and nutritional interventions to enhance sleep. *Sports Medicine, 44*(Suppl 1), S13-23.

Hauri, P. (1968). Effects of evening activity on early night sleep. *Psychophysiology, 4*(3), 266-277.

Hauri, P. (1977). *Current concepts: The sleep disorders*. Kalamazoo: The Upjohn Company.

Hausswirth, C., Louis, J., Aubry, A., Bonnet, G., Duffield, R., & Y, L. E. M. (2014). Evidence of disturbed sleep and increased illness in overreached endurance athletes. *Medicine and Science in Sports and Exercise., 46*(5), 1036-1045.

Heisterberg, M. F., Fahrenkrug, J., Krustrup, P., Storskov, A., Kjaer, M., & Andersen, J. L. (2013). Extensive monitoring through multiple blood samples in professional soccer players. *Journal of Strength and Conditioning Research, 27*(5), 1260-1271.

Helgerud, J., Engen, L., Wisloff, U., & Hoff, J. (2001). Aerobic endurance training improves soccer performance. *Medicine & Science in Sports & Exercise 33*(11), 1925-1931.

Hewitt, A., Norton, K., & Lyons, K. (2014). Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking. *Journal of Sports Sciences, 32*(20), 1874-1880.

Hooper, S. L., & Mackinnon, L. T. (1995). Monitoring overtraining in athletes: Recommendations. *Sports Medicine, 20*(5), 321-327.

Hooper, S. L., Mackinnon, L. T., Howard, A., Gordon, R. D., & Bachmann, A. W. (1995). Markers for monitoring overtraining and recovery. *Medicine & Science in Sports & Exercise, 27*(1), 106-112.

Huikuri, H. V., Makikallio, T., Airaksinen, K. E., Mitrani, R., Castellanos, A., & Myerburg, R. J. (1999). Measurement of heart rate variability: A clinical tool or a research toy? *Journal of the American College of Cardiology., 34*(7), 1878-1883.

Impellizzeri, F. M., Marcora, S. M., Castagna, C., Reilly, T., Sassi, A., Iaia, F. M., & Rampinini, E. (2006). Physiological and performance effects of generic

versus specific aerobic training in soccer players. *International Journal of Sports Medicine, 27*(6), 483-492.

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine & Science in Sports & Exercise, 36*(6), 1042-1047.

Jackowska, M., Dockray, S., Hendrickx, H., & Steptoe, A. (2011). Psychosocial factors and sleep efficiency: Discrepancies between subjective and objective evaluations of sleep. *Psychosomatic Medicine, 73*(9), 810-816.

Julian, R., Hecksteden, A., Fullagar, H. H., & Meyer, T. (2017). The effects of menstrual cycle phase on physical performance in female soccer players. *PLoS One, 12*(3), e0173951.

Juliff, L. E., Halson, S. L., Hebert, J. J., Forsyth, P. L., & Peiffer, J. J. (2018). Longer sleep durations are positively associated with finishing place during a national multiday netball competition. *Journal of Strength and Conditioning Research, 32*(1), 189-194.

Juliff, L. E., Halson, S. L., & Peiffer, J. J. (2015). Understanding sleep disturbance in athletes prior to important competitions. *Journal of Science and Medicine in Sport, 18*(1), 13-18.

Kawada, T. (2008). Agreement rates for sleep/wake judgments obtained via accelerometer and sleep diary: A comparison. *Behavior Research Methods, 40*(4), 1026-1029.

Kelly, D. M., Strudwick, A. J., Atkinson, G., Drust, B., & Gregson, W. (2016). The within-participant correlation between perception of effort and heart rate-based estimations of training load in elite soccer players. *Journal of Sports Science, 34*(14), 1328-1332.

King, M., & Duffield, R. (2009). The effects of recovery interventions on consecutive days of intermittent sprint exercise. *Journal of Strength and Conditioning Research, 23*(6), 1795-1802.

Kleiger, R. E., Stein, P. K., & Bigger, J. T., Jr. (2005). Heart rate variability: Measurement and clinical utility. *Annals of Noninvasive Electrocardiology, 10*(1), 88-101.

Knufinke, M., Nieuwenhuys, A., Geurts, S. A. E., Coenen, A. M. L., & Kompier, M. A. J. (2018). Self-reported sleep quantity, quality and sleep hygiene in elite athletes. *Journal of Science and Medicine in Sport, 27*(1), 78-85.

Kolling, S., Endler, S., Ferrauti, A., Meyer, T., & Kellmann, M. (2016a). Comparing subjective with objective sleep parameters via multisensory actigraphy in german physical education students. *Behavioral Sleep Medicine, 14*(4), 389-405.

Kolling, S., Steinacker, J. M., Endler, S., Ferrauti, A., Meyer, T., & Kellmann, M. (2016b). The longer the better: Sleep-wake patterns during preparation of the World Rowing Junior Championships. *Chronobiology International, 33*(1), 73-84.

Kosmadopoulos, A., Sargent, C., Darwent, D., Zhou, X., & Roach, G. D. (2014). Alternatives to polysomnography (PSG): A validation of wrist actigraphy and a partial-PSG system. *Behavior Research Methods, 46*(4), 1032-1041.

Kripke, D. F., Mullaney, D. J., Messin, S., & Wyborney, V. G. (1978). Wrist actigraphic measures of sleep and rhythms. *Electroencephalography and Clinical Neurophysiology, 44*(5), 674-676.

Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). Physical demands during an elite female soccer game: Importance of training status. *Medicine & Science in Sports & Exercise, 37*(7), 1242-1248.

Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjaer, M., & Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: Implications for sprint performance. *Medicine & Science in Sports & Exercise, 38*(6), 1165-1174.

Krustrup, P., Zebis, M., Jensen, J. M., & Mohr, M. (2010). Game-induced fatigue patterns in elite female soccer. *Journal of Strength and Conditioning Research, 24*(2), 437-441.

Kushida, C. A., Littner, M. R., Morgenthaler, T., Alessi, C. A., Bailey, D., Coleman, J., Jr., Friedman, L., Hirshkowitz, M., Kapen, S., Kramer, M., Lee-Chiong, T., Loube, D. L., Owens, J., Pancer, J. P., & Wise, M. (2005). Practice

parameters for the indications for polysomnography and related procedures: An update for 2005. *Sleep, 28*(4), 499-521.

Lack, L. C., & Wright, H. R. (2007). Chronobiology of sleep in humans. *Cellular and Molecular Life Sciences, 64*(10), 1205-1215.

Lastella, M., Roach, G. D., Halson, S. L., & Sargent, C. (2015). Sleep/wake behaviours of elite athletes from individual and team sports. *European Journal of Applied Physiology, 15*(2), 94-100.

Lazic, S. E. (2010). The problem of pseudoreplication in neuroscientific studies: Is it affecting your analysis? *BMC Neuroscience, 11*, 5.

Le Meur, Y., Hausswirth, C., Natta, F., Couturier, A., Bignet, F., & Vidal, P. P. (2013). A multidisciplinary approach to overreaching detection in endurance trained athletes. *Journal of Applied Physiology, 114*(3), 411-420.

Leatherwood, W. E., & Dragoo, J. L. (2013). Effect of airline travel on performance: A review of the literature. *British Journal of Sports Medicine, 47*(9), 561-567.

Leeder, J., Glaister, M., Pizzoferro, K., Dawson, J., & Pedlar, C. (2012). Sleep duration and quality in elite athletes measured using wristwatch actigraphy. *Journal of Sports Science, 30*(6), 541-545.

Mah, C. D., Mah, K. E., Kezirian, E. J., & Dement, W. C. (2011). The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep, 34*(7), 943-950.

Mallo, J., & Navarro, E. (2008). Physical load imposed on soccer players during small-sided training games. *Journal of Sports Medicine and Physical Fitness, 48*(2), 166-171.

Mann, T. N., Lamberts, R. P., & Lambert, M. I. (2014). High responders and low responders: Factors associated with individual variation in response to standardized training. *Sports Medicine, 44*(8), 1113-1124.

McCraty, R., & Shaffer, F. (2015). Heart rate variability: New perspectives on physiological mechanisms, assessment of self-regulatory capacity, and health risk. *Global Advances in Health and Medicine, 4*(1), 46-61.

McLaren, S. J., Macpherson, T. W., Coutts, A. J., Hurst, C., Spears, I. R., & Weston, M. (2018). The relationships between internal and external measures of training load and intensity in team sports: A meta-analysis. *Sports Medicine, 48*(3), 641-658.

Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., Raglin, J., Rietjens, G., Steinacker, J., Urhausen, A., European College of Sport, S., & American College of Sports, M. (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 & Science in Sports & Exercise, 45*(1), 186-205.

Milanez, V. F., Ramos, S. P., Okuno, N. M., Boullosa, D. A., & Nakamura, F. Y. (2014). Evidence of a non-linear dose-response relationship between training load and stress markers in elite female futsal players. *Journal of Sports Science and Medicine, 13*(1), 22-29.

Milanovic, Z., Sporis, G., James, N., Trajkovic, N., Ignjatovic, A., Sarmento, H., Trecroci, A., & Mendes, B. M. B. (2017). Physiological demands, morphological characteristics, physical abilities and injuries of female soccer players. *Journal of Human Kinetics, 60*, 77-83.

Mischler, I., Vermorel, M., Montaurier, C., Mounier, R., Pialoux, V., Pequignot, J. M., Cottet-Emard, J. M., Coudert, J., & Fellmann, N. (2003). Prolonged daytime exercise repeated over 4 days increases sleeping heart rate and metabolic rate. *Canadian Journal of Applied Physiology, 28*(4), 616-629.

Mohr, M., Krustrup, P., Andersson, H., Kirkendal, D., & Bangsbo, J. (2008). Match activities of elite women soccer players at different performance levels. *Journal of Strength and Conditioning Research, 22*(2), 341-349.

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences, 21*(7), 519-528.

Mohr, M., Krustrup, P., & Bangsbo, J. (2005). Fatigue in soccer: A brief review. *Journal of Sports Sciences, 23*(6), 593-599.

Mourot, L., Bouhaddi, M., Perrey, S., Cappelle, S., Henriet, M. T., Wolf, J. P., Rouillon, J. D., & Regnard, J. (2004). Decrease in heart rate variability with

overtraining: Assessment by the Poincare plot analysis. *Clinical Physiology and Functional Imaging, 24*(1), 10-18.

Mullaney, D. J., Kripke, D. F., & Messin, S. (1980). Wrist-actigraphic estimation of sleep time. *Sleep, 3*(1), 83-92.

Myllymaki, T., Kyrolainen, H., Savolainen, K., Hokka, L., Jakonen, R., Juuti, T., Martinmaki, K., Kaartinen, J., Kinnunen, M. L., & Rusko, H. (2011). Effects of vigorous late-night exercise on sleep quality and cardiac autonomic activity. *Journal of Science and Medicine in Sport, 20*(1 Pt 2), 146-153.

Myllymaki, T., Rusko, H., Syvaoja, H., Juuti, T., Kinnunen, M. L., & Kyrolainen, H. (2012). Effects of exercise intensity and duration on nocturnal heart rate variability and sleep quality. *European Journal of Applied Physiology, 112*(3), 801-809.

Nakamura, F. Y., Pereira, L. A., Rabelo, F. N., Flatt, A. A., Esco, M. R., Bertollo, M., & Loturco, I. (2016). Monitoring weekly heart rate variability in futsal players during the preseason: The importance of maintaining high vagal activity. *Journal of Sports Sciences, 34*(24), 2262-2268.

Nedelec, M., Aloulou, A., Duforez, F., Meyer, T., & Dupont, G. (2018). The variability of sleep among elite athletes. *Sports Medicine - Open, 4*(1), 34.

Nédélec, M., Dawson, B., & Dupont, G. (2019). Influence of night soccer matches on sleep in elite players. *Journal of Strength and Conditioning Research, 33*(1), 174-179.

Nedelec, M., Halson, S., Abaidia, A. E., Ahmaidi, S., & Dupont, G. (2015a). Stress, sleep and recovery in elite soccer: A critical review of the literature. *Sports Medicine, 45*(10), 1387-1400.

Nedelec, M., Halson, S., Delecroix, B., Abaidia, A. E., Ahmaidi, S., & Dupont, G. (2015b). Sleep hygiene and recovery strategies in elite soccer players. *Sports Medicine, 45*(11), 1547-1559.

Nedelec, M., McCall, A., Carling, C., Legall, F., Berthoin, S., & Dupont, G. (2013). Recovery in soccer: Part ii: Recovery strategies. *Sports Medicine, 43*(1), 9-22.

Nimmo, M. A., Ekblom, B., & International Association of Athletics, F. (2007). Fatigue and illness in athletes. *Journal of Sports Science, 25*(Suppl 1), S93-102.

O'Connor, P. J., Breus, M. J., & Youngstedt, S. D. (1998). Exercise-induced increase in core temperature does not disrupt a behavioral measure of sleep. *Physiology & Behavior, 64*(3), 213-217.

Ohayon, M., Wickwire, E. M., Hirshkowitz, M., Albert, S. M., Avidan, A., Daly, F. J., Dauvilliers, Y., Ferri, R., Fung, C., Gozal, D., Hazen, N., Krystal, A., Lichstein, K., Mallampalli, M., Plazzi, G., Rawding, R., Scheer, F. A., Somers, V., & Vitiello, M. V. (2017). National Sleep Foundation's sleep quality recommendations: First report. *Sleep Health, 3*(1), 6-19.

Ohlsson, A., Berg, L., Ljungberg, H., Söderman, K., & Stålnacke, B. (2015). Heart rate distribution during training and a domestic league game in swedish elite female soccer players. *Annals of Sports Medicine and Research, 2(4)1025*.

Otzenberger, H., Gronfier, C., Simon, C., Charloux, A., Ehrhart, J., Piquard, F., & Brandenberger, G. (1998). Dynamic heart rate variability: A tool for exploring sympathovagal balance continuously during sleep in men. *American Journal of Physiology, 275*(3), H946-950.

Pagani, M., Lombardi, F., Guzzetti, S., Rimoldi, O., Furlan, R., Pizzinelli, P., & Malliani, A. (1986). Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. *Circulation, 59*(2), 178-193.

Paquet, J., Kawinska, A., & Carrier, J. (2007). Wake detection capacity of actigraphy during sleep. *Sleep, 30*(10), 1362-1369.

Parak, J., & Korhonen, I. (2015). Accuracy of Firstbeat BodyGuard 2 beat-to-beat heart rate monitor. *Firstbeat*. Retrieved May 8th 2017, from https://www.firstbeat.com/app/uploads/2015/10/white_paper_bodyguard2_final.pdf

Parrado, E., Garcia, M. A., Ramos, J., Cervantes, J. C., Rodas, G., & Capdevila, L. (2010). Comparison of Omega Wave System and Polar S810i to detect

R-R intervals at rest. *International Journal of Sports Medicine, 31*(5), 336-341.

Peterson, B. T., Chiao, P., Pickering, E., Freeman, J., Zammit, G. K., Ding, Y., & Badura, L. L. (2012). Comparison of actigraphy and polysomnography to assess effects of zolpidem in a clinical research unit. *Sleep Medicine, 13*(4), 419-424.

Pichot, V., Roche, F., Gaspoz, J. M., Enjolras, F., Antoniadis, A., Minini, P., Costes, F., Busso, T., Lacour, J. R., & Barthelemy, J. C. (2000). Relation between heart rate variability and training load in middle-distance runners. *Medicine & Science in Sports & Exercise, 32*(10), 1729-1736.

Plews, D. J., Laursen, P. B., Stanley, J., Kilding, A. E., & Buchheit, M. (2013). Training adaptation and heart rate variability in elite endurance athletes: Opening the door to effective monitoring. *Sports Medicine, 43*(9), 773-781.

Postolache, T. T., Hung, T. M., Rosenthal, R. N., Soriano, J. J., Montes, F., & Stiller, J. W. (2005). Sports chronobiology consultation: From the lab to the arena. *Clinics in Sports Medicine, 24*(2), 415-456.

Pumprla, J., Howorka, K., Groves, D., Chester, M., & Nolan, J. (2002). Functional assessment of heart rate variability: Physiological basis and practical applications. *International Journal of Cardiology, 84*(1), 1-14.

Rae, D. E., Stephenson, K. J., & Roden, L. C. (2015). Factors to consider when assessing diurnal variation in sports performance: The influence of chronotype and habitual training time-of-day. *European Journal of Applied Physiology, 115*(6), 1339-1349.

Ramos, G. P., Nakamura, F. Y., Penna, E. M., Wilke, C. F., Pereira, L. A., Loturco, I., Capelli, L., Mahseredjian, F., Silami-Garcia, E., & Coimbra, C. C. (2019). Activity profiles in U17, U20 and senior women's Brazilian National soccer teams during international competitions: Are there meaningful differences? *Journal of Strength and Conditioning Research, 33*(12), 3414-3422.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Azzalin, A., Ferrari Bravo, D., & Wisloff, U. (2008). Effect of match-related fatigue on short-passing ability

in young soccer players. *Medicine & Science in Sports & Exercise, 40*(5), 934-942.

Ranchordas, M. K., Dawson, J. T., & Russell, M. (2017). Practical nutritional recovery strategies for elite soccer players when limited time separates repeated matches. *Journal of the International Society of Sports Nutrition, 14*, 35.

Reilly, T., & Edwards, B. (2007). Altered sleep-wake cycles and physical performance in athletes. *Physiological and Behavior, 90*(2-3), 274-284.

Reilly, T., & Ekblom, B. (2005). The use of recovery methods post-exercise. *Journal of Sports Sciences, 23*(6), 619-627.

Roach, G. D., Schmidt, W. F., Aughey, R. J., Bourdon, P. C., Soria, R., Claros, J. C., Garvican-Lewis, L. A., Buchheit, M., Simpson, B. M., Hammond, K., Kley, M., Wachsmuth, N., Gore, C. J., & Sargent, C. (2013). The sleep of elite athletes at sea level and high altitude: A comparison of sea-level natives and high-altitude natives (ISA3600). *British Journal of Sports Medicine, 47*(Suppl 1), i114-120.

Roberts, S. S. H., Teo, W. P., & Warmington, S. A. (2019). Effects of training and competition on the sleep of elite athletes: A systematic review and meta-analysis. *British Journal of Sports Medicine, 53*(8), 513-522.

Robey, E., Dawson, B., Halson, S., Gregson, W., Goodman, C., & Eastwood, P. (2014). Sleep quantity and quality in elite youth soccer players: A pilot study. *European Journal of Sport Science, 14*(5), 410-417.

Rodriguez-Marroyo, J. A., Villa, G., Garcia-Lopez, J., & Foster, C. (2012). Comparison of heart rate and session rating of perceived exertion methods of defining exercise load in cyclists. *Journal of Strength and Conditioning Research, 26*(8), 2249-2257.

Roomkham, S., Lovell, D., Cheung, J., & Perrin, D. (2018). Promises and challenges in the use of consumer-grade devices for sleep monitoring. *IEEE Reviews in Biomedical Engineering, 11*, 53-67.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold-water immersion on physical performance between successive matches

in high-performance junior male soccer players. *Journal of Sports Sciences, 27*(6), 565-573.

Sadeh, A., Sharkey, K. M., & Carskadon, M. A. (1994). Activity-based sleep-wake identification: An empirical test of methodological issues. *Sleep, 17*(3), 201-207.

Samuels, C. (2008). Sleep, recovery, and performance: The new frontier in high-performance athletics. *Neurologic Clinics, 26*(1), 169-180.

Sandercock, G. R., & Brodie, D. A. (2006). The use of heart rate variability measures to assess autonomic control during exercise. *Scandinavian Journal of Medicine & Science in Sports, 16*(5), 302-313.

Sargent, C., Halson, S., & Roach, G. D. (2014a). Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. *European Journal of Sport Science, 14*(Suppl 1), S310-315.

Sargent, C., Lastella, M., Halson, S. L., & Roach, G. D. (2014b). The impact of training schedules on the sleep and fatigue of elite athletes. *Chronobiology International, 31*(10), 1160-1168.

Sargent, C., Lastella, M., Halson, S. L., & Roach, G. D. (2016). The validity of activity monitors for measuring sleep in elite athletes. *Journal of Science and Medicine in Sport, 19*(10), 848-853.

Sargent, C., & Roach, G. D. (2016). Sleep duration is reduced in elite athletes following night-time competition. *Chronobiology International, 33*(6), 667-670.

Scott, D., & Lovell, R. (2018). Individualisation of speed thresholds does not enhance the dose-response determination in football training. *Journal of Sports Sciences, 36*(13), 1523-1532.

Sehgal, A., & Mignot, E. (2011). Genetics of sleep and sleep disorders. *Cell, 146*(2), 194-207.

Shaffer, F., McCraty, R., & Zerr, C. L. (2014). A healthy heart is not a metronome: An integrative review of the heart's anatomy and heart rate variability. *Frontiers in Psychology, 5*, 1040.

Signal, T. L., Gale, J., & Gander, P. H. (2005). Sleep measurement in flight crew: Comparing actigraphic and subjective estimates to polysomnography. *Aviation, Space, and Environmental Medicine, 76*(11), 1058-1063.

Simpson, N. S., Gibbs, E. L., & Matheson, G. O. (2017). Optimizing sleep to maximize performance: Implications and recommendations for elite athletes. *Scandinavian Journal of Medicine & Science in Sports, 27*(3), 266-274.

Skein, M., Duffield, R., Edge, J., Short, M. J., & Mundel, T. (2011). Intermittent-sprint performance and muscle glycogen after 30 h of sleep deprivation. *Medicine & Science in Sports & Exercise, 43*(7), 1301-1311.

Skein, M., Duffield, R., Minett, G. M., Snape, A., & Murphy, A. (2013). The effect of overnight sleep deprivation after competitive rugby league matches on postmatch physiological and perceptual recovery. *International Journal of Sports Physiology and Performance, 8*(5), 556-564.

Stanley, J., Peake, J. M., & Buchheit, M. (2013a). Cardiac parasympathetic reactivation following exercise: implications for training prescription. *Sports Medicine, 43*(12), 1259-1277.

Stanley, J., Peake, J. M., & Buchheit, M. (2013b). Consecutive days of cold water immersion: Effects on cycling performance and heart rate variability. *European Journal of Applied Physiology, 113*(2), 371-384.

Stepanski, E. J., & Wyatt, J. K. (2003). Use of sleep hygiene in the treatment of insomnia. *Sleep Medicine Reviews, 7*(3), 215-225.

Swinbourne, R., Gill, N., Vaile, J., & Smart, D. (2016). Prevalence of poor sleep quality, sleepiness and obstructive sleep apnoea risk factors in athletes. *European Journal of Sport Science, 16*(7), 850-858.

Tarvainen, M. P., Niskanen, J. P., Lipponen, J. A., Ranta-Aho, P. O., & Karjalainen, P. A. (2014). Kubios HRV: Heart rate variability analysis software. *Computer Methods and Programs in Biomedicine, 113*(1), 210-220.

TaskForce. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use: Task Force of the European

Society of Cardiology and the North American Society of Pacing and Eletrophysiology. *European Heart Journal, 17*(3), 354-381.

Taylor, L., Chrismas, B. C., Dascombe, B., Chamari, K., & Fowler, P. M. (2016). Sleep medication and athletic performance: The evidence for practitioners and future research directions. *Frontiers in Physiology, 7*, 83.

Taylor, S. R., Rogers, G. G., & Driver, H. S. (1997). Effects of training volume on sleep, psychological, and selected physiological profiles of elite female swimmers. *Medicine & Science in Sports & Exercise, 29*(5), 688-693.

Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W. (2015). Monitoring fatigue during the in-season competitive phase in elite soccer players. *International Journal of Sports Physiology and Performance., 10*(8), 958-964.

Trewin, J., Meylan, C., Varley, M. C., & Cronin, J. (2018). The match-to-match variation of match-running in elite female soccer. *Journal of Science and Medicine in Sport, 21*(2), 196-201.

Tryon, W. W. (2004). Issues of validity in actigraphic sleep assessment. *Sleep, 27*(1), 158-165.

Van Dongen, H. P. (2005). Analysis of inter- and intra-individual variability. *Journal of Sleep Research, 14*(2), 201-203.

Vescovi, J. D., & Favero, T. G. (2014). Motion characteristics of women's college soccer matches: Female Athletes in Motion (FAiM) study. *International Journal of Sports Physiology and Performance, 9*(3), 405-414.

Vitale, J. A., Banfi, G., Galbiati, A., Ferini-Strambi, L., & Torre, A. (2019). Effect of night-game on actigraphy-based sleep quality and perceived recovery in top-level volleyball athletes. *International Journal of Sports Physiology and Performance, 14*(2), 265-269.

Vitale, J. A., Bonato, M., Galasso, L., La Torre, A., Merati, G., Montaruli, A., Roveda, E., & Carandente, F. (2017). Sleep quality and high intensity interval training at two different times of day: A crossover study on the influence of the chronotype in male collegiate soccer players. *Chronobiology International, 34*(2), 260-268.

Wallen, M. B., Hasson, D., Theorell, T., Canlon, B., & Osika, W. (2012). Possibilities and limitations of the Polar RS800 in measuring heart rate variability at rest. *European Journal of Applied Physiology, 112*(3), 1153-1165.

Waterhouse, J., Atkinson, G., Edwards, B., & Reilly, T. (2007). The role of a short post-lunch nap in improving cognitive, motor, and sprint performance in participants with partial sleep deprivation. *Journal of Sports Sciences, 25*(14), 1557-1566.

Watson, A. M. (2017). Sleep and athletic performance. *Current Sports Medicine Reports, 16*(6), 413-418.

Watson, N. F., Badr, M. S., Belenky, G., Bliwise, D. L., Buxton, O. M., Buysse, D., Dinges, D. F., Gangwisch, J., Grandner, M. A., Kushida, C., Malhotra, R. K., Martin, J. L., Patel, S. R., Quan, S. F., & Tasali, E. (2015). Recommended amount of sleep for a healthy adult: A joint consensus statement of the American Academy of Sleep Medicine and Sleep Research Society. *Sleep, 38*(6), 843-844.

Weippert, M., Kumar, M., Kreuzfeld, S., Arndt, D., Rieger, A., & Stoll, R. (2010). Comparison of three mobile devices for measuring R-R intervals and heart rate variability: Polar S810i, Suunto t6 and an ambulatory ECG system. *European Journal of Applied Physiology, 109*(4), 779-786.

Xie, L., Kang, H., Xu, Q., Chen, M. J., Liao, Y., Thiyagarajan, M., O'Donnell, J., Christensen, D. J., Nicholson, C., Iliff, J. J., Takano, T., Deane, R., & Nedergaard, M. (2013). Sleep drives metabolite clearance from the adult brain. *Science, 342*(6156), 373-377.

Youngstedt, S. D., Kripke, D. F., & Elliott, J. A. (1999). Is sleep disturbed by vigorous late-night exercise? *Medicine & Science in Sports & Exercise, 31*(6), 864-869.

Appendixes

Ethical approval

Ethical approval for the prospective monitoring conducted in this thesis was granted by the Ethics Committee of the University of Porto, University of Porto, Portugal (Ethics Protocol Number – CEFADE 03.2017).

Ethical approval was obtained for prospective monitoring prior to the beginning of this Ph.D., given by the Ethics Committee of the Faculty of Porto, University of Porto, Portugal. This approval provides the ability to prospectively collect data which may be utilized in research studies such as those completed in this thesis.

U.PORTO
FACULDADE DE DESPORTO
UNIVERSIDADE DO PORTO

Ethics Committee

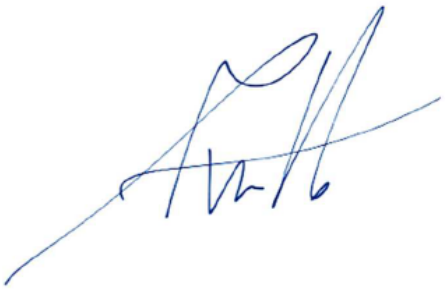
ETHICS OPINION

Process **CEFADE 03.2017**

The Ethics Committee of the Faculty of Sport from the University of Porto analyzed the project entitled "Autonomic cardiac function and sleep responses to training and match load of elite female footballers", presented by MSc. Júlio Alexandre da Costa. Considering the project's characteristics, as well as the competence of the research team, the Ethics Committee addresses a positive opinion, because the ethical principles that govern this type of scientific work are respected.

Porto and Faculty of Sport, 24th March, 2017

The chairman of the Ethics Committee,

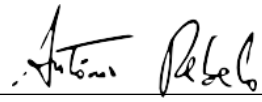


José Alberto Ramos Duarte

Disclosure Statement

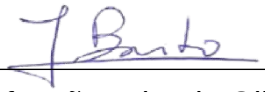
I hereby declare that no potential conflict of interest was reported by the authors during the preparation of any studies conducted in this thesis.

Supervisor

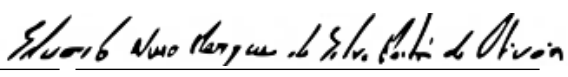


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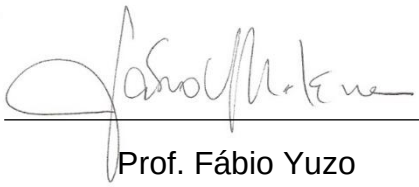


Prof. João Brito de Oliveira Fernandes, Ph.D.

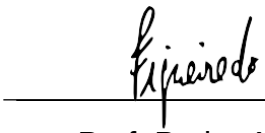


Prof. Eduardo Nuno Marques da Silva Moitas de Oliveira, Ph.D.

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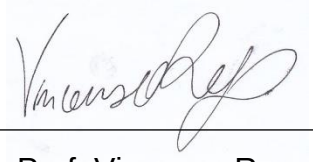
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Dr. Prof. Ovídio António Pereira da Costa Ph.D.



Prof. Vincenzo Rago, Ph.D.

Awards

During the doctorate, some studies of the present thesis were awarded:

- FIFA Research Scholarship
- Best oral Communication Presentation. *XIVº Congresso Nacional de Medicina Desportiva* 2018 Braga, Portugal.
- Best Work in the category: Physiology and Biomechanics of Sports: *"Padrões do sono e atividade autonómica cardíaca noturna após treinos e jogos realizados a diferentes horas do dia em futebolistas femininas"*. *Prémios Ciências do Desporto. Comité Olímpico de Portugal (COP) e Fundação Millennium BCP*.
- Pessoas UP recognition by University of Porto (Pessoa UP February 2019). [https://noticias.up.pt/pessoas-da-up/julio-costa/]

Responsabilities

- Study design and methodology of the original studies included in the thesis;
- Apply for scientific research scholarships/grants;
- Obtain ethical approval and consent forms;
- Recruit participants in female soccer team(s), including the National Portuguese team;
- All arrangements for data collection;
- Data collection;
- Analyse all the data collected, under the supervision of my supervisors and collaborators/specialists;
- Data interpretation;
- Write the original studies and submit them for publication in *peer-reviewed* journals (with preference in Quartile 1 *peer-reviewed* journals);
- Prepare oral presentations of the results from the original studies to be presented in scientific national/international congresses.

Skills acquired as a result of this Ph.D.

- Knowledge on how to delineate research studies, how to analyse data and how to interpret scientific research results;
- Knowledge on how to apply for scientific research scholarships/grants;
- Knowledge on training and match load (internal and external), (nocturnal) HRV and sleep (accelerometer) monitorization in athletes, during “real world scenarios”;
- Acquisition of training and match load analysis techniques;
- Acquisition of (nocturnal) HRV analysis techniques;
- Acquisition of sleep duration and quality analysis techniques;
- Knowledge on how to assist coaches and practitioners to identify sleep and nocturnal HRV disturbances during official competitions, especially during periods of highly congested fixtures;
- Knowledge on recruiting human participants for scientific research studies;
- Writing skills;
- Oral presentation skills;
- Developed abilities to scientifically communicate in two different languages (Portuguese and English);
- Extension of networking contacts.

Additional research outputs

2019

Costa, J. A. (2019). É Tempo de Acordar: Monitorização do Sono em Atletas Femininas. *Revista de Medicina Desportiva*, *10(5)*, 45-47.

É Tempo de Acordar: Monitorização do Sono em Atletas Femininas



Dr. Júlio Costa
Centro de Investigação, Formação, Inovação e Intervenção em Desporto, Universidade do Porto, Faculdade de Desporto. Portugal Football School, Federação Portuguesa de Futebol, Oeiras, Portugal

Introdução

Ao longo dos últimos anos, o futebol feminino tem ganho uma enorme popularidade. Consequentemente, o número de competições internacionais, de ligas desportivas profissionais e recreativas para atletas do sexo feminino de várias faixas etárias, tem aumentado de forma significativa. Isto proporcionou novas oportunidades para treinar e competir.

Apesar da crescente popularidade e profissionalização os estudos científicos com atletas do sexo feminino é ainda limitado em comparação com atletas do sexo masculino, especialmente em áreas relacionadas como a otimização do desempenho e métodos de recuperação, em diferentes cenários de competição e treino. Este assunto torna-se ainda mais relevante, dado que em alguns países as atletas (profissionais e não-profissionais) usualmente iniciam os treinos muito tarde, perto da hora de dormir, devido aos seus compromissos diários (ex. trabalho e/ou universidade) que têm que ser conciliados com os horários de treino e de jogo.[1-3] Assim, é necessário investigar métodos que sejam sensíveis e não invasivos para monitorizar os padrões de sono em atletas, a fim de promover uma melhor higiene do sono e, consequentemente, uma melhor recuperação.[4]

Sono e atletas de futebol feminino

O sono é reconhecido como um componente fundamental para o bem-estar e desempenho dos atletas, particularmente durante o período competitivo (época desportiva).[5] No futebol feminino, as atletas estão constantemente expostas a programas de treino e jogos muito congestionados, principalmente com sessões de treino próximos da hora de deitar[2,3], que podem reduzir o tempo total do sono[6] e prejudicar os processos de recuperação.[7]

Um dos aspetos fundamentais para a recuperação do atleta é obter suficiente quantidade e qualidade de sono.[8] De facto, atletas e treinadores de várias modalidades desportivas, incluindo futebol, selecionaram o sono como a estratégia mais importante de recuperação do atleta.[9] Um mínimo de 7-9 horas do tempo total de sono e eficiência do sono (ou seja, percentagem do tempo total do sono) ≥85% por noite é geralmente recomendado para promover uma melhor saúde e função cognitiva em adultos com idades ente os 18 a 60 anos.[10,11] Embora ainda não exista um consenso relativamente à quantidade do sono que um atleta deva obter para manter um ótimo desempenho[12], os atletas que dormem menos de 7 horas por noite podem ter maior probabilidade obter lesão.[8,13]

Estudos anteriores[2,3,14] analisaram a relação entre o exercício e o sono, sugerindo que alguns fatores podem afetar o sono e a recuperação, tais como o cronótipo (ritmo circadiano de um indivíduo) do atleta, ou a carga e/ou a hora do dia da prática do exercício físico. Em alguns dos nossos estudos[2,3], embora as jogadoras tenham acumulado sono adequado (≥7h), foi possível observar diminuição na duração do sono após sessões de treino realizados à noite (21h00)[2,3] ou após jogos realizados à noite (19h00; resultados não publicados). De facto, foi observada redução consistente no tempo total de sono e atraso no tempo de latência do sono (ou seja, tempo que demorou a adormecer) após sessões de treino realizados à noite em comparação com os dias de repouso.[2,3] Estes resultados estão de acordo com outros estudos, onde se observou que os jogadores em dias de jogos concluídos antes das 18h00 apresentaram sono adequado,[10,11] ao contrário dos dias de jogo e sessões de treino realizados após às 18h00, em que o tempo total de sono se reduziu significativamente.[5,15]

Vitale *et al.* (2018) observaram que a quantidade e a qualidade do sono foram menores durante a noite imediatamente após o jogo realizado à noite, em comparação com as noites anteriores ou posteriores, tanto em atletas do sexo feminino, como do sexo masculino. No nosso estudo com a Seleção Nacional Portuguesa feminina, (resultados não publicados), durante os nove dias do torneio internacional (Algarve Cup 2018), enquanto grupo, as jogadoras apresentaram valores adequados na quantidade e qualidade do sono em todos os dias de treino e jogos. No entanto, verificou-se redução significativa do tempo total do sono e da eficiência do sono após o jogo realizado à noite (19h00) em comparação com os restantes jogos realizados durante o dia (15h00). Desta forma, os nossos resultados sugerem que o exercício realizado perto da hora de deitar[2,3], podem colocar dificuldades no tempo para adormecer. Uma explicação para os resultados observados poderá ser a extensão da hora de deitar provocada pelo horário/programação das sessões de treino e/ou jogos.[16-18] Assim, é importante aplicar estratégias para promover sono e recuperação adequados, especialmente após as competições que são realizadas à noite, e educar os atletas sobre o assunto.[8]

Adicionalmente, a redução do tempo total do sono após diferentes cenários de jogos (ou seja, jogos jogados em casa ou fora) deve ser uma preocupação, já que a recuperação após o jogo poderá ficar comprometida.[19] Devido ao tempo necessário para viajar, os padrões de sono após os jogos fora podem ser mais afetados do que os jogos realizados em casa.[20] Assim, as alterações nos contextos dos jogos, podem alterar os padrões "normal" de sono dos jogadores (ou seja, alteração da localização, hora do início do jogo, e viajem).[5]

Num estudo[2] realizado em jogadoras da primeira divisão do campeonato nacional Português, as atletas

apresentaram horas de deitar mais tarde (+36 min) e latências mais elevadas (+5min) após os jogos fora em comparação em comparação com os jogos em casa. O facto de as atletas terem chegado mais tarde às suas casas após os jogos fora e a influência das atividades sociais após os jogos fora[21], uma vez que as atletas tiveram que viajar juntas de regresso para casa, podem justificar os resultados obtidos. Longas viagens aéreas (ex. intercontinentais), podem aumentar os sintomas de *jet-lag* e prejudicar o estado de humor[22] e posteriormente afetar os índices de sono em atletas.[21] No entanto, estas questões não parecem estar relacionadas unicamente com a distância percorrida *per se*[23], dado que as jogadoras não tiveram que viajar (autocarro) durante mais que três horas após os jogos fora.[2]

Sabe-se ainda que a exposição à luz pode ter um impacto negativo no sono, estendendo o início do sono, reduzindo o tempo total de sono e aumentando a latência.[21] Uma possível explicação para os resultados observados nos nossos estudos,[2,3] ou seja, a redução no tempo total do sono e extensão do tempo para adormecer, quando comparando o exercício realizado à noite com os exercícios realizados durante o dia ou com os dias de repouso, poderá ter sido a exposição do atleta à luz emitida no estádio. Durante os dias de treino as atletas foram expostas a >1200 lux e 5600K, com a luz policromática brilhante ≥1000 lux, sendo suficiente para estimular efeitos de alerta/vigilância durante o sono.[24]

Monitorização do sono em atletas

Para detetar e controlar os distúrbios do sono é importante monitorizar os hábitos de sono e as perceções sobre o sono, através de medidas subjetivas e/ou objetivas.[25] No entanto, as necessidades do sono em atletas permanecem desconhecidas, dado que a monitorização neste tipo de população não é muito comum.[26] O equipamento recomendado para monitorizar o sono é a polissonografia, que recorre ao uso de elétrodos superficiais para monitorizar os parâmetros fisiológicos, como atividade cerebral, muscular, cardíaca e respiratória.[27] A polissonografia é particularmente útil para investigar patologias do sono, incluindo distúrbios respiratórios do sono[28] e distúrbios do sono causados por concussões.[29] No entanto, a polissonografia é dispendiosa e requer equipamentos de laboratório especializados, sendo pouco prático a sua utilização em atletas no contexto real.[30] A actigrafia, por outro lado, usa acelerómetros colocados em dispositivos portáteis para registar movimentos que, analisados através de algoritmos, estimam a qualidade e a quantidade do sono.[31] A actigrafia é menos dispendiosa, é não invasiva e pode ser utilizada nas rotinas de treino/jogos (geralmente duas semanas de monitorização).[32] Assim, a actigrafia é o método mais acessível para monitorizar objetivamente o sono dos atletas durante a noite.[30] Os "diários do sono" são também utilizados para registar a data/hora de início e término para todos os períodos de sono (ou seja, sono noturno e sestas diárias).[32]

Higiene do sono para atletas: recomendações

Os atletas devem utilizar uma boa higiene do sono para maximizar o sono. Algumas das estratégias para um bom sono são:[33-36]

- O quarto deve estar entre os 18-20°C, escuro e silencioso;
- Evitar ver televisão, utilizar os *tablets* e telemóveis, pelo menos, uma hora antes de ir dormir;
- Evitar café, álcool, e nicotina cerca de 4-5h antes de ir dormir;
- Implementar estratégias de relaxamento 30-60 min antes de ir dormir (ex., relaxamento progressivo muscular);
- Manter um horário regular para dormir e para acordar (ou seja, criar uma rotina de sono, procurando deitar e acordar sempre à mesma hora do dia);
- Sestas apropriadas (~30 min e não no final de tarde);
- Estar consciente da ingestão de alimentos e líquidos antes de ir dormir (ou seja, não ir para a cama depois de consumir muitos líquidos, pois pode levar com que o sono seja interrompido para idas à casa de banho);

SPMD

16.º Curso de Pós-Graduação em Medicina Desportiva

Direção do Curso:
Prof.ª Doutora Maria João Cascais
Prof. Doutor Ovídio Costa

Destinatários:
Licenciados em Medicina / Mestrado Integrado em Medicina (Portugal, Brasil e PALOP)

Programa Geral:
- Bioenergética
- Fisiologia do exercício
- Cardiologia desportiva
- Pneumologia e imunoalergologia
- Clinica medica no exercício e desporto
- Anatomia funcional & traumatologia
- Reabilitação desportiva
- Prevenção de lesões
- Nutrição
- Psicologia desportiva
- Exame medico desportivo
- Farmacologia e doping
- Populações especiais e exercício em condições extremas
- Prescrição de exercício

Duração:
Outubro de 2019 a Julho de 2020, sábados, das 9h às 13h e 14h às 18h

Regime de frequência:
Presencial ou Videoconferência em direto ou diferido

Candidaturas:
Em www.spmd.pt até 15 de Setembro de 2019.
O número de vagas é limitado.

- Evitar dormir muito tarde nos dias de "folga" (ou seja, nos dias sem treino e/ou jogo).

Conclusão

Existe a necessidade em utilizar métodos sensíveis e não invasivos (tais como os acelerómetros) para monitorizar os padrões de sono, a fim de promover melhor higiene do sono e consequentemente a eficiente recuperação, especialmente quando as sessões ou os jogos são realizados perto da hora de deitar. Um dos aspetos importantes dos nossos estudos e novidade na investigação no sono em atletas do futebol feminino é o uso dos acelerómetros durante o sono num "cenário real". Cada atleta realizou as gravações de acelerometria de punho nas suas casas, para que os hábitos do sono não fossem limitados pelos procedimentos do estudo e assim conferir uma maior validade ecológica à investigação.

Sugere-se que atletas e treinadores organizem, não apenas o cronograma dos treinos e de competição, mas também tenham em consideração as rotinas de sono para facilitar uma recuperação/desempenho mais eficiente.

Financiamento

Fundação para a Ciência e a Tecnologia [SFRH/BD/128531/2017];
FIFA Research Scholarship 2017 (International Centre for Sports Studies [CIES] and Fédération Internationale de Football Association [FIFA]).

O autor declara ausência de conflito de interesses

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Bibliografia em:
www.revdesportiva.pt (A Revista Online)

15º Congresso Nacional de Medicina Desportiva – Programa

18 e 19 de outubro – Portimão

Sexta-feira		
08:00 h	Abertura	
08:30 h	Sessão de boas-vindas	
09:00 h	Doença renal e exercício	
	O desportista com patologia renal e prevenção da doença renal	Marco Mendes
	Planos de exercício físico quantificado: efeitos metabólicos, estruturais e funcionais	João Viana
	Sindrome cardio-renal, síndroma metabólico, diabetes e exercício padronizado	Patrícia Branco
11:00 h	Hot topics em cardiologia desportiva	
	Avaliação do praticante com dor torácica	Paulo Dinis
	Avaliação do praticante com síncope	António Freitas
	Avaliação do praticante com arritmia	Carlos Morais
11:45 h	Exercício na prescrição da doença cardíaca: o que há de novo	Hélder Dores
13:00 h	Cerimónia de abertura	
14:30 h	Estado do conhecimento. Tendências futuras	
	Salvar o menisco. Quando suturar?	Ricardo Telles de Freitas
	Medicina regenerativa e tendinopatia: "prp advanced" – tendência para o futuro?	Palestrante tbc
	Medicina regenerativa e tendinopatia: ondas de choque – estado do conhecimento	Rita Tomás
	Cirurgia do ligamento cruzado anterior. Abordagem do atleta de elite.	João Pedro Oliveira
16:15 h	Perspetiva multidisciplinar na abordagem do atleta lesionado	
	Como lida o fisioterapeuta com as questões psicológicas e de retorno à pratica do atleta lesionado?	Rogério Pereira
	Tertúlia multidisciplinar. Groin pain, o triângulo das bermudas da medicina desportiva?	Carlos Magalhães, Sérgio Gomes, João Pedro Araújo, Rúben Ferreira
Sábado		
09:00 h	Monitorização. Cargas de treino	
	Centros de alto rendimento (car) – investigação, formação e oferta serviços.	João Beckert
	Monitorização das cargas treino em modalidades individuais	palestrante tbc
	"Red flags" – pode a monitorização das cargas treino ser útil na redução das lesões?	João Brito
11:00 h	Recuperação pós esforço. Diversidade processos	
	Sono e técnicas relaxação	João Paulo Almeida
	Nutrição e suplementação pós esforço	Rodrigo Abreu
	Crioterapia	Francisco Tavares
14:30 h	Qualidade organizacional e formativa	
	Processo de certificação a entidades formadoras – o processo na Federação Portuguesa de Futebol	Júlio Vieira/Tiago Brás
	Requisitos para o apoio médico-desportivo na certificação a entidades formadoras (FPF)	Paulo Beckert/José Pedro Marques
	Estrutura e organização de um departamento médico (alta competição)	Lluis Til
16:00 h	Um olhar 360º na organização, gestão e formação dos recursos	Painel de convidados

Bibliografia

1. Costa JA, Brito J, Nakamura FY, Oliveira EM, Rebelo AN. *Effects of Late-Night Training on "Slow-Wave Sleep Episode" and Hour-by-Hour--Derived Nocturnal Cardiac Autonomic Activity in Female Soccer Players.* Int J Sports Physiol Perform. 2018; 13(5):638-644.
2. Costa JA, Brito J, Nakamura FY, Figueiredo P, Oliveira E, Rebelo A. *Sleep patterns and nocturnal cardiac autonomic activity in female athletes are affected by the timing of exercise and match location.* Chronobiol Int. 2018; 1-14.
3. Costa JA, Brito J, Nakamura FY, Oliveira EM, Costa OP, Rebelo AN. *Does Night-Training Load Affect Sleep Patterns and Nocturnal Cardiac Autonomic Activity in High-Level Female Soccer Players?* Int J Sports Physiol Perform. 2018; 1-26.
4. Meeusen R, Duclos M, Foster C, *et al. 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.* Med Sci Sports Exerc. 2013; 45(1):186-205.
5. Fullagar H, Skorski S, Duffield R, Julian R, Bartlett J, Meyer T. *Impaired sleep and recovery after night matches in elite football players.* J Sports Sci. 2016; 34(14):1333-1339.
6. Lastella M, Roach GD, Halson SL, Sargent C. *Sleep/wake behaviours of elite athletes from individual and team sports.* Eur J Sport Sci. 2015; 15(2):94-100.
7. Vitale JA, Banfi G, Galbiati A, Ferini-Strambi L, Torre A. *Effect of Night-Game on Actigraphy--Based Sleep Quality and Perceived Recovery in Top-Level Volleyball Athletes.* Int J Sports Physiol Perform. 2018; 1-14.
8. Roberts SSH, Teo WP, Warmington SA. *Effects of training and competition on the sleep of elite athletes: a systematic review and meta--analysis. Roberts SSH, Teo W-P, Warmington SA.* Br J Sports Med2019; 53:513–522.
9. Fallon KE. *Blood tests in tired elite athletes: expectations of athletes, coaches and sport science/sports medicine staff.* Br J Sports Med. 2007; 41(1):41-44.
10. Watson NF, Badr MS, Belenky G, *et al. Recommended Amount of Sleep for a Healthy Adult: A Joint Consensus Statement of the American Academy of Sleep Medicine and Sleep Research Society.* Sleep. 2015; 38(6):843-844.
11. Ohayon M, Wickwire EM, Hirshkowitz M, *et al. National Sleep Foundation's sleep quality recommendations: first report.* Sleep Health. 2017; 3(1):6-19.
12. Sargent C, Lastella M, Halson SL, Roach GD. *The impact of training schedules on the sleep and fatigue of elite athletes.* Chronobiol Int. 2014; 31(10):1160-1168.
13. Milewski MD, Skaggs DL, Bishop GA, *et al. Chronic lack of sleep is associated with increased sports injuries in adolescent athletes.* J Pediatr Orthop. 2014; 34(2):129-133.
14. Vitale JA, Bonato M, Galasso L, *et al. Sleep quality and high intensity interval training at two different times of day: A crossover study on the influence of the chronotype in male collegiate soccer players.* Chronobiol Int. 2017; 34(2):260-268.
15. Nedelec M, Aloulou A, Duforez F, Meyer T, Dupont G. *The Variability of Sleep Among Elite Athletes.* Sports Med Open. 2018; 4(1):34.
16. Fullagar H, Skorski S, Duffield R, Meyer T. *The effect of an acute sleep hygiene strategy following a late-night soccer match on recovery of players.* Chronobiol Int. 2016; 33(5):490-505.
17. Sargent C, Roach GD. *Sleep duration is reduced in elite athletes following night-time competition.* Chronobiol Int. 2016; 33(6):667-670.
18. Juliff LE, Halson SL, Peiffer JJ. *Understanding sleep disturbance in athletes prior to important competitions.* J Sci Med Sport. 2015; 18(1):13-18.
19. Skein M, Duffield R, Minett GM, Snape A, Murphy A. *The effect of overnight sleep deprivation after competitive rugby league matches on postmatch physiological and perceptual recovery.* Int J Sports Physiol Perform. 2013; 8(5):556-564.
20. Fowler P, Duffield R, Vaile J. *Effects of simulated domestic and international air travel on sleep, performance, and recovery for team sports.* Scand J Med Sci Sports. 2015; 25(3):441-451.
21. Nedelec M, Halson S, Abaidia AE, Ahmaidi S, Dupont G. Stress, *Sleep and Recovery in Elite Soccer: A Critical Review of the Literature.* Sports Med. 2015; 45(10):1387-1400.
22. Bonnar D, Bartel K, Kakoschke N, Lang C. *Sleep Interventions Designed to Improve Athletic Performance and Recovery: A Systematic Review of Current Approaches.* Sports Med. 2018; 48(3):683-703.
23. Carriço S, Skorski S, Duffield R, Mendes B, Calvete F, Meyer T. *Post-match sleeping behavior based on match scheduling over a season in elite football players.* Science and Medicine in Football. 2017; 2(1):9-15.
24. Cajochen C. *Alerting effects of light.* Sleep Med Rev. 2007;11(6):453-464.
25. Myllymaki T, Kyrolainen H, Savolainen K, *et al. Effects of vigorous late-night exercise on sleep quality and cardiac autonomic activity.* Journal of Sleep Research 2011; 20(1 Pt 2):146-153.
26. Roky R, Herrera CP, Ahmed Q. *Sleep in athletes and the effects of Ramadan.* Journal of Sports Science. 2012; 30 Suppl 1:S75-84.
27. Kushida CA, Littner MR, Morgenthaler T, *et al. Practice parameters for the indications for polysomnography and related procedures: an update for 2005.* Sleep. 2005; 28(4):499-521.
28. George CF, Kab V, Levy AM. *Increased prevalence of sleep-disordered breathing among professional football players.* N Engl J Med. 2003; 348(4):367-368.
29. Gosselin N, Lassonde M, Petit D, *et al. Sleep following sport-related concussions.* Sleep Med. 2009; 10(1):35-46.
30. Sargent C, Lastella M, Halson SL, Roach GD. *The validity of activity monitors for measuring sleep in elite athletes.* J Sci Med Sport. 2016; 19(10):848-853.
31. Ancoli-Israel S, Cole R, Alessi C, Chambers M, Moorcroft W, Pollak CP. *The role of actigraphy in the study of sleep and circadian rhythms.* Sleep. 2003; 26(3):342-392.
32. Halson SL. *Sleep Monitoring in Athletes: Motivation, Methods, Miscalculations and Why it Matters.* Sports Med. 2019 May 15. doi: 10.1007/s40279-019-01119-4
33. Halson SL. *Sleep in elite athletes and nutritional interventions to enhance sleep.* Sports Med. 2014; 44 Suppl 1:S13-23.
34. Stepanski EJ, Wyatt JK. *Use of sleep hygiene in the treatment of insomnia.* Sleep Med Rev. 2003; 7(3):215-225.
35. Nedelec M, Halson S, Delecroix B, Abaidia AE, Ahmaidi S, Dupont G. *Sleep Hygiene and Recovery Strategies in Elite Soccer Players.* Sports Med. 2015; 45(11):1547-1559.
36. Vitale KC, Owens R, Hopkins SR, Malhotra A. *Sleep Hygiene for Optimizing Recovery in Athletes: Review and Recommendations.* Int J Sports Med. 2019; 40(8):535-543.

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Participants consent forms

Consentimento Informado, Livre e Esclarecido para Participação num Projeto de Investigação

Leia por favor atentamente a seguinte informação e se concordar com o que lhe é apresentado, queira assinar este documento.

Eu, Júlio Alejandro Henriques da Costa, aluno regularmente matriculado no programa doutoral em ciências do desporto da Universidade do Porto da Faculdade de Desporto (FADE-UP), sob orientação do Prof. Dr. António Natal Ph.D, e co-orientação do Prof. Dr. João Brito e Prof. Dr. Eduardo Oliveira encontro-me a efetuar uma investigação para tese de doutoramento intitulado: "*Autonomic cardiac function and sleep responses to training and match load of elite female footballers*", para obtenção de grau de doutor (Ph.D) em ciências do desporto.

Esta investigação tem como objetivo investigar as respostas da função autonómica cardíaca e do sono às cargas de treino e jogo, em jogadoras de elite de futebol (Estudos prospetivos I-IV). Para esta finalidade, a influência da realização de exercício físico na variabilidade da frequência cardíaca (VFC) e nas respostas ao sono serão analisados em detalhe em futebolistas de elite do sexo feminino. Serão estudados a utilidade e o interesse prático da utilização de parâmetros do sono como ferramenta de avaliação da fadiga. Além disso, o potencial uso da VFC como indicador do estado de recuperação das atletas será analisado. Finalmente, serão explorados a relação entre o esforço percebido, o impulso de treino e os parâmetros referidos (VFC) durante a realização de esforço submáximo.

Neste contexto venho solicitar a vossa excelência a sua participação no preenchimento deste questionário. A informação recolhida será anónima e confidencial e apenas utilizada, exclusivamente, para o presente estudo, pelo que não se deve identificar ao longo do mesmo, salvaguardando desta forma a sua privacidade.

Nome do inquirido: _____

Assinatura: _____

Data: ___/____/_____

Consentimento Informado

Consentimento Informado, Livre e Esclarecido para Participação num Projeto de Investigação

Leia por favor, atentamente, a seguinte informação e se concordar com o que lhe é apresentado, queira assinar este documento.

A presente recolha de dados insere-se no projeto: "*Autonomic cardiac function and sleep responses to training and match load of elite female soccer players*".

O principal objetivo do projeto de investigação centra-se em investigar as respostas da função autonómica cardíaca através da variabilidade da frequência cardíaca e da qualidade e quantidade do sono (ambos os métodos considerados não invasivos) em relação às cargas de treino e de jogo em atletas femininas de elite de futebol.

Neste contexto, vimos solicitar a sua participação no preenchimento deste consentimento. A informação recolhida será anónima e confidencial e apenas utilizada, exclusivamente, para o presente estudo, pelo que não se deve identificar ao longo do mesmo, salvaguardando desta forma a sua privacidade.

Nome: _____

Assinatura: _____

Data: ___/____/_____

FIFA Research Scholarship Final Report accepted and approved

CIES | CENTRE INTERNATIONAL D'ÉTUDE DU SPORT

Mr Júlio Alejandro Henriques Da Costa

Porto
Portugal

Neuchâtel, 1 October 2019

TO WHOM IT MAY CONCERN:

The International Centre for Sports Studies (CIES), which has been entrusted to manage and implement the FIFA Research Scholarship on behalf of FIFA, hereby confirms that

Mr. Júlio Alejandro Henriques Da Costa, born on 26 June 1991,

Doctoral and research student in Sports Science at the Faculty of Sports at the University of Porto (FADE, UP), has been awarded a FIFA Research Scholarship grant in 2017. The CIES further confirms that the Research Final Report has been accepted and approved in September 2019.

Should you require further information, please do not hesitate to contact us.

Yours sincerely,

Vincent Schatzmann
General Secretary

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