Match-running performance of elite female soccer players: The factors affecting performance and training applications

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Abstract

Due to the unpredictable nature of soccer, a match is open to a variety of different factors that may affect player movement, such as environmental or within match situational factors. When practitioners examine match performances, these factors should be considered when providing feedback to coaches and players, and this data should inform the training prescribed. Therefore, this thesis aimed to answer the question, "what are the effects of environmental and situational factors on player movement in international women's soccer matches?" The secondary question of this thesis is "what is the training approach utilised to peak for international tournaments where such variables are in play?" A comprehensive systematic review of the literature revealed match-factors might affect movement particularly with respect to situational factors. Meanwhile, altitude and temperature reduced match-running in full match and peak period analyses, highlighting the difficulty of playing in these environments. Altitude, temperature, opposition ranking, match outcome and congested schedules were chosen as match-factors for analysis.

The aim of the first study was to examine the effects of match-factors on the match-running of elite female soccer players. The main findings observed small to moderate decreases in all metrics (Effect Size - ES = -0.83 to -0.16) in high temperatures and lower total distance at high altitude (ES = -0.54). Playing lower-ranked teams in a draw resulted in moderately greater high-speed running (ES = 0.89), whilst winning against higher-ranked opponents produced moderately greater total distance and low-speed running (ES = 0.75). The second investigation aimed to examine the effect of match-factors in the Peak match-running of elite female soccer players. Less peak distance (ES -0.85) and high-speed running (ES = -0.27), with less distance, high-speed running and accelerations (ES = -0.44 to -0.37) was observed. Drawing a match, compared to winning or losing, increased total distance and high-speed running (ES = 0.32 to 0.43). The aim of the third study was to examine the match-running of full match, and the effect of early or late substitutions. We found that late substitutes completed a greater rate of total distance, high-speed running, accelerations and PlayerLoad than full match and early substitutes (ES = 0.33 to 1.22). The aim of the fourth investigation was to examine changes in match-running, perceived wellness and neuromuscular fatigue during a period of fixture congestion. Mostly trivial findings in the full match analysis were observed, however, with closer examination lower total distance

(ES = -0.69) from the first to last match of tournament in players who competed in all matches was observed. Furthermore, self-reported sleep hours declined (ES = -0.94) from the first to the last match, indicating the need for tracking perceived player wellness throughout successive matches. The aim of the fifth study was to examine the effects of 2250 m of altitude on match-running in elite female youth soccer players. Total distance, low-speed running and PlayerLoad were very likely to almost certainly less at altitude (ES = -2.26 to -0.29). In addition, ratings of perceived exertion and heart rate metrics were very likely to almost certainly increased following a submaximal running test at altitude compared to sea-level. Finally, application of match data to the preparation for international tournaments indicated greater training load during preparation for the 2016 Olympics compared to 2015 World Cup during all training blocks (ES -5.92 to -0.66). Following the taper block, all wellness variables were improved compared to both the training and friendly blocks (ES = 0.59 to 2.55). In addition, a delay of approximately one- to two-days was observed between the exposure to a load and the reporting of a change in perceived wellness reported.

In summary, match-running is affected by a variety of factors associated with soccer matches. Practitioners should account for these factors when providing feedback to players and coaches, whilst also utilising this information in preparation for matches. This may be by way of loading or coach guidance to understand the effects of a particular factor in the performance of players. Where possible, the inclusion of perceived ratings of wellness should be included to examine the effects of a training programme or a period of successive matches. These ratings should be collected daily in the morning and examined with respect to training loads, either as a rating of perceived exertion of global positioning metrics. Overall, this thesis provides a thorough understanding of match-running in elite females, whilst providing practical recommendations for the preparation of players for competition.

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Attestation of 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 (except where explicitly defined in the acknowledgements), nor 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.

Chapters 2-9 of this thesis are separate papers that have either been published, submitted to peer-reviewed journals for consideration or are currently being prepared for submission. My contribution and that contributed by the various co-authors to each of these papers are outlined at the beginning of each chapter. All co-authors have approved the inclusion of the joint work in this doctoral thesis.

Joshua Sean William Trewin

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Co-authored works

Table 1: Co-authored works

Chapter publication reference		Author %
Chapter 2	Trewin J, Meylan C, Varley MC, Cronin J. The influence of situational and environmental factors on match-running in soccer: A systematic review. Science and Medicine in Football. 2017; https://doi.org/10.1080/24733938.2017.1329589	JT 85% CM 5% MV 5% JC 5%
Chapter 3	Trewin J, Meylan C, Varley MC, Cronin J. The match-to-match variation of match-running in elite female soccer. Journal of Science and Medicine in Sport. 2017; http://dx.doi.org/10.1016/j.jsams.2017.05.009	JT 85% CM 10% MV 2.5% JC 2.5%
Chapter 4	Trewin J, Meylan C, Varley MC, Cronin J, Ling D. The effect of match-factors on the running performance of elite female soccer players.	JT 80% CM 5% MV 5% JC 5% DL 5%
Chapter 5	Trewin J, Meylan C, Varley MC, Cronin J, Tsai. The effect of match-factors on the peak running performance of elite female soccer players.	JT 80% CM 5% MV 5% JC 5% MT 5%
Chapter 6	Trewin J, Meylan C, Varley MC, Cronin J, Ling D. Brief report: A comparison of match-running performances of full game, early and late substitutes in elite female soccer.	JT 80% CM 10% MV 5% JC 2.5% DL 2.5%
Chapter 7	Trewin J, Meylan C, Tsai MC, Varley MC, Cronin J. Is athlete readiness and match-running performance affected during a congested match schedule in elite female soccer?	JT 80% CM 7.5% MT 7.5% MV 2.5% JC 2.5%
Chapter 8	Trewin J, Meylan C, Tsai MC, Manson S, Varley MC, Cronin J. The reduction of match-running in elite female youth soccer players at 2250 m	JT 80% CM 5% MV 5% MT 5% SM 2.5% JC 2.5%
Chapter 9	Trewin J, Meylan C, Tsai MC, Varley MC, Cronin J. An examination of training load and readiness during five-weeks preparation for two international tournaments in international female soccer players.	JT 80% CM 7.5% MT 5% MV 5% JC 2.5%

We, the undersigned, agree to the percentage of contribution to the chapters identified above:

Supervisors

Prof John Cronin	Dr Cesar Meylan	Dr Matthew C. Varley
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Ethics approval

Ethical approval for the longitudinal monitoring conducted in this thesis was granted by the Human Research Ethics Board of the University of Victoria, British Columbia, Canada (Ethics Protocol Number – 14-037).

Ethics were obtained for longitudinal monitoring prior to the beginning of this PhD. This was completed by the Canadian Sport Institute – Pacific and University of Victoria. This approval provides the ability to longitudinally collect data which may be utilised in research studies such as those completed in this thesis.

Chapter 1: Introduction and rationalisation

Why do we monitor player movement?

The monitoring of player movement in team sports has become widespread, particularly at elite levels [1, 2]. Technological advances have seen the use of global positioning systems (GPS), semi-automatic multi-camera systems and local positioning systems to monitor athlete movement [3, 4]. Wearable technology, such as GPS, has become the common system of choice at all levels of sport, with the ability to utilise this data in training and match situations in a variety of locations, with match data often used to individualise training load [5]. Initially, training load management revolved around reducing player loads in an attempt to minimise risk of injury [6, 7]. This has changed in recent years, with the view of exposing athletes to higher loads, through progressive overload [1, 8-10]. Therefore, an in-depth understanding of possible match loads is important for practitioners to forecast the load their players should be exposed to in training. Monitoring of match data allows practitioners to build a database of normative values for individual players and to further be used to monitor the changes in performance in relation to a variety of factors. Factors such as altitude, temperature, opposition rankings, score-lines, formations and possession have been suggested to affect match-running [11-15]. For example, playing a higher ranked team might increase overall match-running, whilst a match at altitude might have a small effect on high-speed running. Analysis of these factors can provide practitioners with a greater understanding of the game and allow technical coaches to have appropriate expectations of what their players can actually achieve within a match. This thesis will primarily focus on international women's soccer, as few studies have utilised this elite level of athletes [16].

Interpreting movement of soccer players

The use of pre-set absolute speed thresholds is common, however, speed thresholds based on objective physiological measures relative to each player may provide better individualisation of high-speed distances [17, 18]. Therefore, it would be inappropriate to examine female soccer utilising the same speed thresholds as the male game [18]. Researchers have examined the idea of relative player thresholds in activity profile analyses in professional soccer players [17]. The velocity at which an individual's second ventilatory threshold occurred was used to define high-speed running, as this represented the threshold at which the athlete was unable to sustain exercise at a certain level [17]. Researchers comparing relative and absolute speed thresholds observed median second ventilatory threshold speed as 4.2 $m \cdot s^{-1}$, which was 1.3 $m \cdot s^{-1}$ slower than arbitrary thresholds utilised [17]. More recent studies have adopted a high-speed threshold of 4.0 $m \cdot s^{-1}$ [19, 20], however, high-speed running is still often categorised as >5.5 $m \cdot s^{-1}$ by some authors [21, 22]. The use of relative thresholds is, however, a time-consuming process and may not be suitable for all situations, particularly in an international environment where time with players is restricted. Authors have suggested an absolute high-speed threshold of 15 $km \cdot h^{-1}$ be utilised in future research, based on an elite male analysis [17]. The subject environment (elite international players) and the time-consuming nature of setting relative thresholds lend more to the utilisation of absolute speed thresholds. However, physiological variables identified utilising field tests to create female specific speed thresholds may be the most appropriate method. Researchers have suggested the use of mean aerobic speed and anaerobic speed reserve obtained via locomotor field tests as a simple time effective method of setting physiologically based speed thresholds [23, 24]. Furthermore, where implementation of relative thresholds is not possible, an alternative method might be used as a percentage of game normative data for a given player to define external training loads, such as distance sprinted or the number of high-speed efforts [5]. This method may help to account for differences in physical capacity, whilst, being time-efficient by not requiring laboratory or field-based tests to be completed regularly. It might also provide strength and conditioning coaches with a monitoring tool better suited to individualise training load and avoid excessive fatigue or injury.

Examination of distances covered at specific speed thresholds may underestimate energy expenditure by 6-8% [25-27]. Maximal accelerations from low speeds can match, or even exceed, the power output required to maintain high speeds [26] and may occur eight times more than sprinting in games [28]. In addition to the metabolic demands, maximal accelerations do not need to occur at high speeds to be physically challenging. Less than 1% of maximal acceleration efforts (>2.78 $m \cdot s^{-2}$) reached the sprint speed threshold (6.9 $m \cdot s^{-1}$) in elite male soccer players [28]. Considering that high accelerations and decelerations have been linked with large muscle damage [29], velocity based thresholds may not account for the factors most responsible for post-match neuromuscular fatigue [30]. Therefore, the inclusion of accelerations and decelerations, obtained via GPS, appear warranted to provide an indication of the metabolic demands of soccer.

The demands of female soccer competition have been examined both at domestic [31-33] and at international (youth and senior) levels [31, 32, 34]. Researchers have reported distances in total (7000-10300 m), at low-speeds (2900-9000 m), high-speed (590-665 m) and sprinting (167-337 m) [31-34]. However, due to the chaotic nature of soccer, match-running may be affected by a variety of situational [12, 19, 20, 35-37] and environmental factors [11, 13, 38]. Therefore, it is imperative a thorough understanding of these factors is gained and practitioner's account for these factors when analysing match performances.

Match Factors

Given the nature of the game a number of factors can influence the way the game is played and the outcomes. These factors may be environmental, or situational. Environmental challenges are ever present, with the 2010 and 2014 FIFA Men's World Cups played at high altitudes and in high temperatures [39, 40]. Total distance (~10%) and accelerations (~4%) were observed to decline at altitude (1600-3600 m), compared to sea-level, in elite male and female youth players [11, 38, 41]. Lower (15%) high-speed running has been observed in elite male soccer players at temperatures greater than 21°C, compared to less than 21°C [13]. Only one previous investigation has observed female National Collegiate Athletic Association soccer players whilst playing at altitude (1839 m), compared to sea-level, the researchers reporting a decrease in total (~-13%, $p<0.001$) and high-speed running (~-11%, $p=0.039$) distances [41].

Opposition ranking is a situational factor which has been investigated, however varying definitions make it difficult to compare data [14, 42-44]. Nonetheless, greater total distance (2.5%) and high-speed running distance (5.3-7.7%), in addition to greater high-speed running distance with the ball (1.2-19%), has been observed when playing more successful teams compared to less successful teams [14, 42-44]. Elite female soccer players were reported to cover the greatest match-running across all movement thresholds against similarly ranked opponents [36]. The analysis of match-outcomes in relation to in match-running, Spanish Premier League players were observed to cover greater high-speed (16%)

and sprint distance (5.4%) in a loss, whilst in a win the distances run at low (5.6%) and moderate (9.1%) speeds were higher [42]. Additionally, a greater percentage of time spent in high-speed movement (1.3%, p = 0.004) was reported in English Premier League attackers whilst winning a match [15]. Lastly, researchers have considered the idea of a congested schedule affecting match-running due to small recovery periods between the first and subsequent matches, with often trivial findings being reported [45, 46]. These findings have been questioned within the elite male game, with less than 41% of players completing 90 minutes during back-to-back matches [47].

With the exception of two studies, all the research has been on male soccer players, highlighting the need for more research in to changes in female soccer. Physiological differences in sex may exacerbate performance changes in response to environmental factors, such as thermoregulation and menstrual cycle changes in core temperature, and further research is needed to document the changes in match-running performance in response to the environment for female soccer players [48, 49]. Whilst the scientific quality of the female studies presented requires improvement to provide a greater understanding in to how factors affect female soccer players.

Peak match-running periods

Researchers have questioned the current training techniques in elite sport, highlighting that worst-case scenarios are often not considered [9, 50]. The worst-case scenario is described as the period of highest intensity, or match-running, possible during a given match which often exceeds the average of the entire match. The examination of smaller time periods, such as a match half or 15 minute periods, is becoming more prevalent in match-analysis research [21, 51, 52]. High-speed running in the first half of EPL matches have been observed to directly impact high-speed running in the second half (~6.2% decrease) [51]. Whilst, following the most intense 5 min period, high-speed running has been observed to significantly decrease [21]. Whilst the ability to repeatedly produce high-speed efforts is essential in soccer, periods of reduced high-speed activity is common [21, 51]. When using 15 min periods, high-speed running has been observed to substantially decrease in the opening 15 min of the second half [52]. When re-examination of the same 15 min period using 5 min periods was undertaken, a substantial decrease in high-speed running during the first 5 min of the second half, with trivial reductions in subsequent 5 min periods was observed. The use of 15 min periods may not be sensitive enough to detect the intricacies of match-running patterns [53]. Furthermore, a rolling analysis has been suggested as the most accurate method of identifying peak periods of match-running, with 5 min periods (such as 0-5, 5-10, 10-15 and so on) shown to underestimate peak periods compared to a rolling 5 min period analysis [54]. A rolling period analyses is a given time-period, such as 5 min, from each individual data point of a match of which there are 10 per second in common commercial GPS units. Researchers have recently shown the benefits of using a moving average to identify peak periods across a different time periods [55], thus highlighting the need to analyse a rolling peak 5 min periods within match-analysis research.

Training load

Training load has been described as the product of volume and intensity of a training modality [56]. Training load can be both external, as prescribed by the coach (such as 4 v 4 small sided games for 4 mins), or internal, relating to the physiological stress of the prescribed external load. Monitoring of the internal training load is an important aspect of any form of training [56]. Rating of perceived exertion (RPE) is an inexpensive approach to monitoring internal training load of athletes through the use of a 1-10, or 6-20, scale [57]. When multiplied by the session duration, a single number can be used to quantify internal training load called session-RPE [58]. One study has utilised this method to examine the relationship between session-RPE and heart rate based training loads [56], these authors suggesting the use of session-RPE was largely to very-largely correlated ($r = 0.50$ to 0.85) to heart rate training loads described using three different methods (Bannister's TRIMP, Edwards' training load, and Lucia's TRIMP). Furthermore, utilising the same heart rate training load methods, quantification of training load in female soccer players was also very-largely correlated ($r = 0.83$-0.85) to session-RPE values [59]. Utilising such an approach would seem a valid method of quantifying internal training load using an inexpensive yet reliable method.

The importance of appropriate loading cannot be underestimated, particularly for elite international teams leading into international tournaments, such as World Cups or Olympic Games. Researchers so far have focused on the loading of professional teams throughout out a season [60, 61]. These studies have analysed the training load on specific days relative to match-day, with values typically at their lowest on the day prior to match-day [60, 61]. However, how loading is periodised prior to the first match of an international tournament has not been reported. Periodisation in elite team sports is not well known, however, performance improvements have been shown in elite individual sports, such as swimming, following a taper [62]. A taper refers to a reduction in training volume in conjunction with a maintenance of frequency and intensity [62, 63]. During a training phase, the change in loading can affect perceived wellness. By tracking a range of subjective variables, a practitioner can monitor the effects of a training programme on aspects such as fatigue, soreness and sleep quality. It is understood that accumulation of high-speed running over a three-day period is moderately related to ratings of fatigue in elite male soccer players [64]. However, it could be hypothesised that a longer accumulation period, or chronic load, might have a greater effect on the perceived wellness of an athlete. Particularly during a phase of heavy loading, with research having already shown a change in sleeping patterns in professional rugby league players [65].

Performance Constructs

It should be noted the physical performance is only one aspect of true soccer performance. This thesis will focus solely on the physical performance, but it should be considered as part of overall performance, including both technical and tactical performance [66]. As an example, the amount of high-speed running distance completed is greater for higher ranked teams in FIFA rankings, compared to lower ranked teams [67]. In the Italian Serie A, there was no difference between the higher ranked and lower ranked teams, with the differentiator being high-speed running with the ball [14]. An interaction between physical and technical performance may be present in soccer. Researchers should take this in to account when making recommendations on physical match performances.

Rationale and significance of the thesis

Male soccer has an exhaustive amount of research examining the various factors that may influence the movement of players. Altitude [11, 38], heat [68, 69] and situational factors such as possession, formation and score line have been examined [12, 20, 70]. Furthermore, the effect of a congested schedule has also been investigated [71, 72]. However, information regarding the effects of these factors, and in combination with each other, on the movement of female athletes has not been studied. Elite female soccer competition is increasing, with multiple tournaments, comprising of three or more games played during a short period. A small body of research has investigated player movement in female soccer [31-34], however, the influence of environmental and situational factors on player movement has not been examined. In addition, the investigation of training load leading into international tournaments has not been studied. In female soccer, these periods are crucial for not only physical development but also tactical cohesion. Appropriate periodisation is therefore important for players to be not only physically at their peak, but also reach the first game with minimal fatigue.

It can be hypothesised that the findings from the male game may not be transferable to the female given the physiological differences between sexes. Specifically, females have smaller body mass and body surface area compared to males and a larger surface area-to-mass ratio; a higher percentage of body fat which is potentially disadvantageous in the heat; and finally the phases of the menstrual cycle can increase core body temperature [48]. The makeup of the male cardiac system also allows for greater oxygen delivery allowing for larger maximal oxygen consumption (VO_{2max}) [49]. Given these differences research examining the changes in running performance of elite female soccer players would seem warranted. With the increased interest in the women's game, the understanding of these effects would be beneficial to the planning of training and implementation of strategies to accommodate, or overcome, the factors of interest. The overarching question of this thesis, therefore is, "what are the effects of environmental and situational factors on player movement in international women's soccer matches?" The secondary question of this thesis is "what are the training methods utilised to peak for international tournaments where such variables are in play?"

The aims of this thesis are:

1. To review the current literature regarding the effects of environmental and situational factors on activity profiles.
2. To quantify the match-to-match variation of elite female match-running performances.

3. To investigate the effect of match-factors on the running performance of elite female soccer players during a full match.
4. To investigate the effects of match-factors on the within-match-running performance of elite female soccer players using a rolling 5-min analysis technique.
5. To examine the difference in match-running between full match, early and late substitute players.
6. To examine the change in readiness and performance during a period of successive matches in elite female soccer players.
7. To examine the change in performance of elite female soccer players during matches at 2250 m of altitude.
8. To quantify the training stress of elite female soccer players during preparations for two international tournaments.

The findings of this thesis will enable strength and conditioning coaches to plan specific training programs, whilst also providing information to guide tactical strategies for coaches, in elite female soccer.

Thesis organisation

The thesis is structured into five sections to address the key areas related to the purpose of the thesis (Figure 1). The thesis consists of one literature review (Chapter 2) and six investigations (Chapters 3-8), all of which have been submitted, or are in the process of being submitted, to international peer-reviewed journals. As such, each chapter is therefore presented in the format of the journals to which they were submitted. For consistency, all referencing is in *Sports Medicine* Journal format (*Vancouver* style) with a single citation summary presented at the end of the thesis.

Section one addresses the current knowledge surrounding the effects of different match-factors on match-running performance in soccer. Section two examines the match-to-match variation and compares the match-running performance of full match and substitute players in elite female soccer. Section three examines the changes observed in match-running performance using a full match and peak match-running analysis in relation to selected match-factors. Section four provides further insight with respect to two specific match-factors on player readiness and match-running performance. Section five applies match-data to the training environment in a detailed description of loading leading up to international tournaments in elite female soccer, and provides a summary of the findings of the thesis.

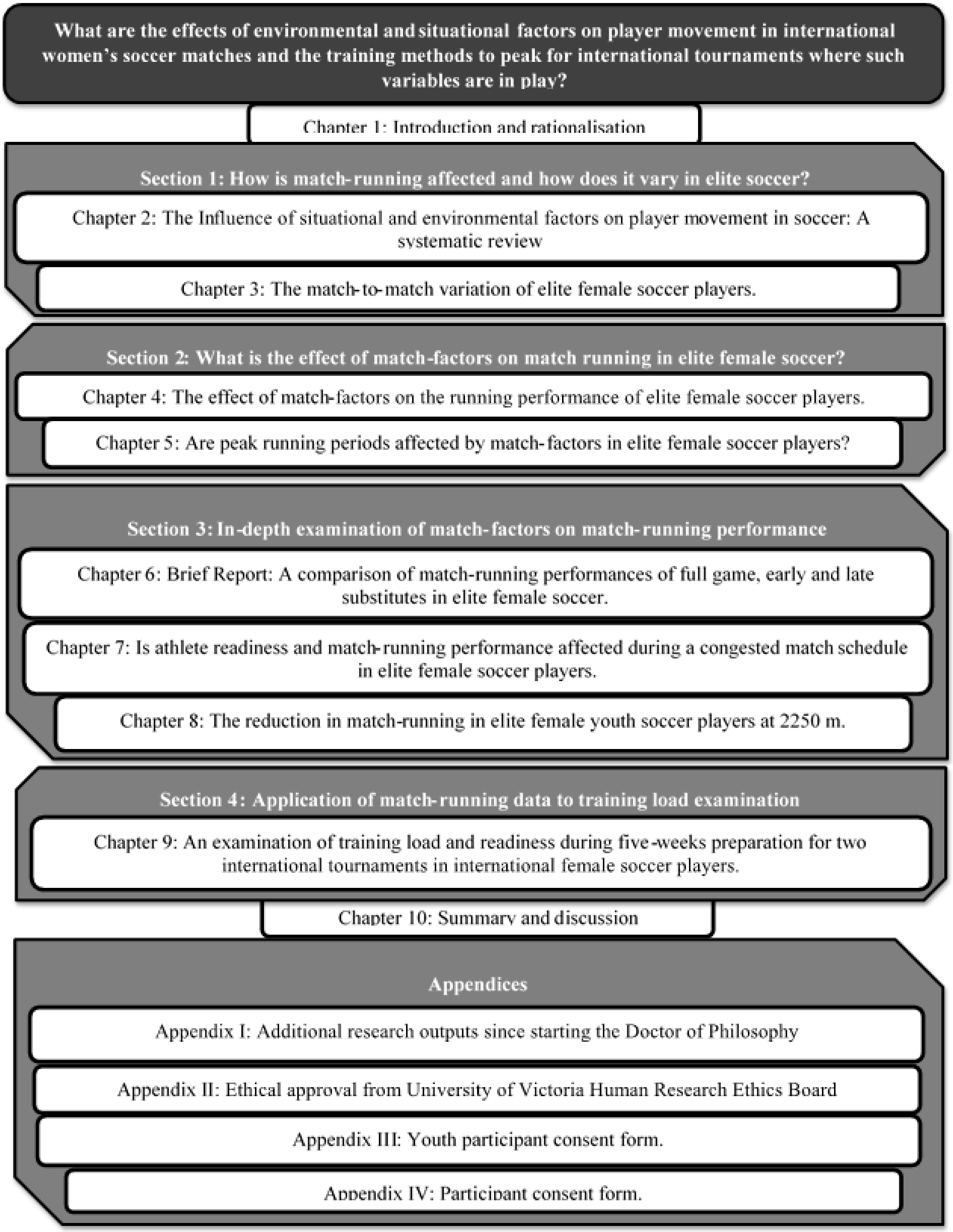

Figure 1: *Thesis chapter flow*

Section 1: How is match-running affected and how does it vary in elite soccer?

Chapter 2: The Influence of situational and environmental factors on player movement in soccer: A systematic review

Chapter 3: The match-to-match variation of match-running in elite female soccer

Chapter 2: The influence of situational and environmental factors on player movement in soccer: A systematic review

This chapter comprises the following paper published in *The Journal of Science and Medicine in Football.*

Reference:

Trewin J, Meylan C, Varley M, Cronin J. The influence of situational and environmental factors on match-running in soccer: A systematic review. Science and Medicine in Football. 2017;1(2):183-94; https://doi.org/10.1080/24733938.2017.1329589

Author Contribution:

Trewin J, 85%; Meylan C, 5%; Varley MC, 5%; Cronin J, 5%.

Prelude

A common practice amongst researchers and practitioners to monitor the match-running of elite players via electronic tracking systems. GPS technology is becoming more prevalent, with the ability for practitioners to monitor both match and training loads with the one system. As soccer is a global game, the playing environments can differ, and heat and altitude are factors that may impact player match-running performance. Furthermore, situational match-factors, such as opposition rankings, the match outcome or score line, formations and percentage of possession, may also influence match-running performances. A thorough understanding of how these factors may affect performance is required for practitioners to provide appropriate feedback to players and coaches for match preparation and post-match data interpretation. Furthermore, this understanding can help practitioners provide appropriate training stimuli to prepare players for a given match. Therefore, the purpose of this chapter is to systematically review the current literature on the environmental and situational factors affecting match-running in soccer. This chapter will provide a rationale for the selection of specific match-factors that will be examined within this thesis.

Introduction

The use of technology in soccer to monitor, forecast and adjust the cardiovascular and neuromuscular stress (i.e. external running load) imposed by training, or matches, is increasing in prevalence [73, 74]. Modern semi-automatic multi-camera analysis systems (e.g. Prozone® and Amisco®) monitor physical performance, in combination with technical activities (e.g. ball possession, passes, tackles) during matches [75]. Similarly, the use of global positioning system (GPS) technology is common across a range of football codes, which allows tracking of match-running and accelerometry-based metrics [76], and recently has been cleared for use in official competitive matches (e.g. FIFA World Cup). Past reviews have discussed the use of technology and match-running analysis in soccer [75-78], however, the effect of specific factors on match-running demands have only briefly been reviewed [79] and requires further investigation.

Soccer is subject to various situational and environmental factors, proposed to affect match-running [37, 79]. Within match, situational factors, such as formation [19, 20], ball possession [12, 43, 80], opposition ranking [36, 44, 81] and match status [15] have been assessed with varying effects observed. Environmental factors such as altitude [11, 38, 39, 41] and temperature [13, 40, 69] have been found to affect match-running due to physiological limitations and possible sub-conscious pacing whilst performing in these environments [82]. As soccer is an ever-changing game performed in a range of environmental conditions, understanding the effects of these factors is required to optimize player performance. Finally, players can be subject to periods of fixture congestion, playing multiple matches within a short period of time [71, 72, 83]. However, exposure to congested schedules has been questioned, along with the current methodology used to examine these periods [47, 84].

As match-running is of interest to practitioners in terms of performance analysis, team strategies, and load management, it is pertinent to investigate the effect of different factors on match-running. The authors believe all factors should be considered in combination, rather than independently, whilst it is also not feasible to include all factors (e.g. grass vs artificial turf) in a detailed review such as this. Therefore, the primary aim of this review is to examine, in a systematic way, the effects of selected situational and environmental factors on the match-running of soccer players. This review will elaborate on the findings of Paul, Bradley [79] by specifically expanding on the match-factors affecting match-running.

Recommendations will be provided to improve future match-analysis and research protocols with the aim of better understanding elite soccer performances.

Methods

Data source

Studies investigating match-running, where situational variables were examined, or where games were played in a range of outdoor environments, were included in this review. A systematic literature search of electronic databases (PubMed, EBSCOHost, and Web of Science) was conducted for the time period of Jan 2000 until October 2015. Further articles known to the authors that were not identified during the literature search were also included for analysis. The search terms included football or soccer combined with performance analysis, movement analysis, activity profiles, time-motion analysis, congested schedule, GPS, Prozone, and Amisco.

Study selection

After eliminating duplicates, titles were screened for eligibility. Titles which indicated the investigation was not relevant to the scope of this review were eliminated. Following title screening, search results were independently screened by two researchers against the eligibility criteria. Abstracts were examined as to relevance, with articles retrieved for further review if required. Following independent screening, the two researchers discussed any differences and finalized the studies for inclusion in this review. Papers were only included if they were in English, with abstracts of conference proceedings excluded. Studies were included if they reported physical performance outcome measures and assessed the effects of situational (formation, possession, match outcome, team success or congested schedule) or environmental factors (altitude or temperature). Studies that utilised outdated time-motion techniques, such as notation of manual video analysis [32, 67], were also excluded. Following screening, a total of 27 studies were included in this review (Figure 2) with the characteristics and quality index (Table 2) of selected studies shown in Table 3. The methods of Castellano, Alvarez-Pastor [75], where a detailed explanation can be found, were used to rate study quality out of nine criteria, with a maximum score of ten.

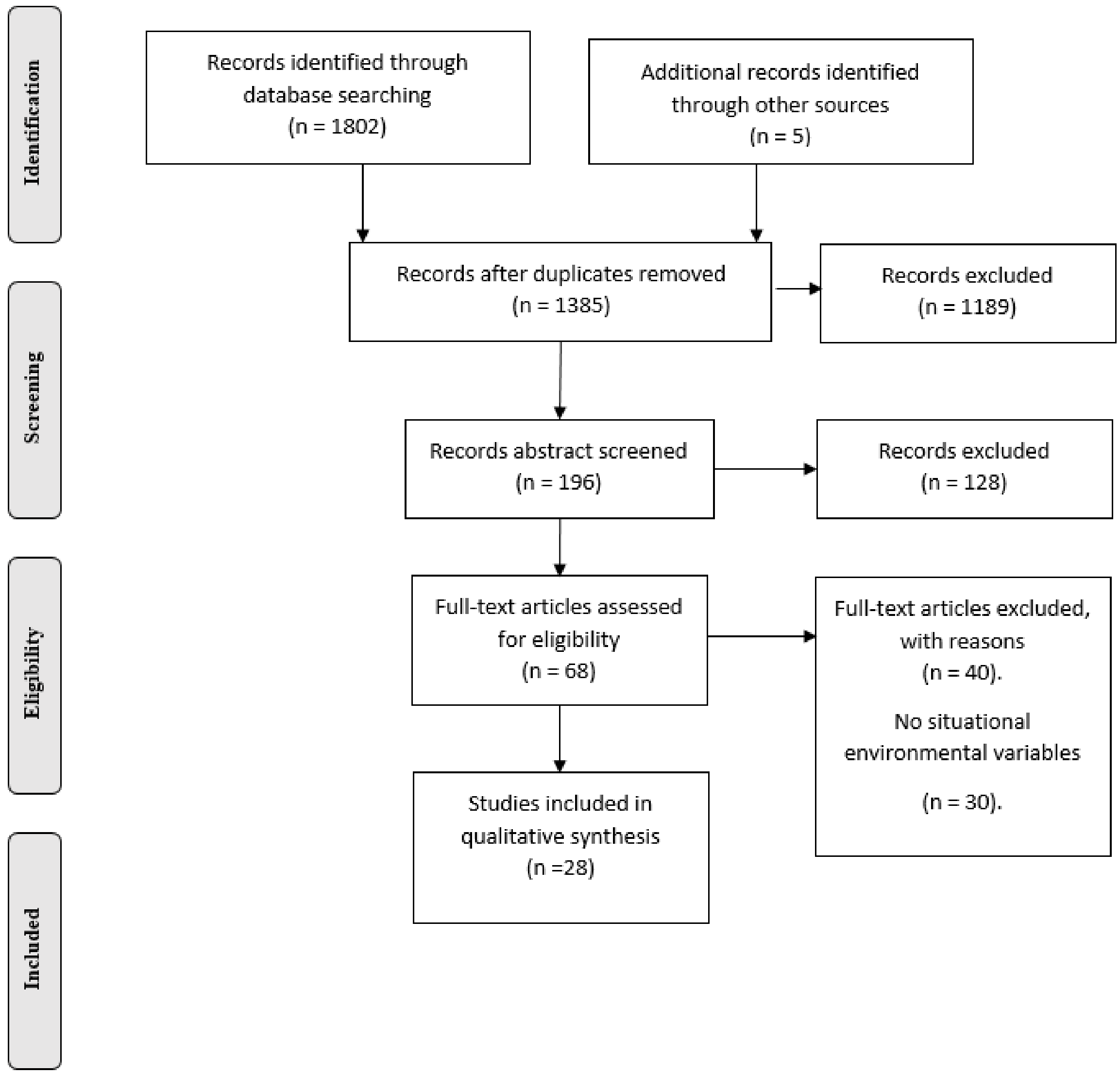

Figure 2: Flow-diagram of study identification and exclusion process.

Table 2: Study quality criteria

Criteria adapted from Castellano et al., (2014) (3)			
Q1 The study is published in a peer-reviewed journal or book	No = 0	Yes = 1	
Q2 The study is published in an indexed journal	No = 0	Yes = 1	
Q3 The study objective(s) is/are clearly set out	No = 0	Yes = 1	
Q4 Either the number of recordings is specified or the distribution of players/recordings used is known	No = 0	Yes = 1	
Q5 The duration of player recordings (an entire half, a complete match, etc.) is clearly indicated.	No = 0	Yes = 1	
Q6 A distinction is made according to player positions	No = 0	Yes = 1	
Q7 The reliability/validity of the instrument is not stated, is mentioned or is measured	Not Stated = 0	Mentioned = 1	Measured = 2
Q8 Certain situational variables (e.g. match status, match location, type of competition or quality of the opponent) are taken into account	No = 0	Yes = 1	
Q9 The results are clearly presented	No = 0	Yes = 1	

Table 3: Study participant characteristics and quality ratings (total out of 10)

First Author (year)	Level	Participants (Files)	System	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Total
Arruda (2014)	Elite Male U15 Youth	15 (N.S.)	GPS	1	1	1	0	1	0	1	1	1	7
Aughey (2013)	Male Elite age group National	27 (104)	GPS	1	0	1	1	1	0	0	1	1	6
Bohner (2015)	NCAA Women	6 (18)	GPS	1	0	1	0	1	0	0	0	1	4
Bradley (2011)	Male English Premier League	153	ProZone	1	1	1	1	1	1	1	1	1	9
Bradley (2013)	Male English Premier League	810	ProZone	1	1	1	1	1	1	1	1	1	9
Carling (2010)	Male French League 1	28 (228)	Amisco	1	1	1	1	1	1	0	1	1	8
Carling (2011)a	Male French League 1	9 (339)	Amisco	1	0	1	1	1	1	0	1	1	7
Carling (2011)b	Male French League 1	21 (297)	Amisco	1	1	1	1	1	1	0	1	1	8
Da Mota (2015)	Fifa Men’s World Cup	346 (792)	Optical Tracking	1	1	1	1	1	1	0	0	1	7
Dellal (2011)	Male European Premier Leagues	(5938)	Amisco	1	1	1	1	0	1	0	1	1	7
Dellal (2013)	Male French League 1	16	Amisco	1	0	1	0	1	0	1	1	1	6
Di Salvo (2009)	Male English Premier League	563 (7355)	ProZone	1	0	1	1	1	1	1	1	1	8
Djaoui (2014)	Male Elite European	16 (132)	Amisco	1	1	1	1	1	1	0	1	1	8
Dupont (2010)	Male Scottish Premier League	32 (3696)	Amisco	1	1	1	1	1	1	2	1	1	10
Folgado (2015)	Male English Premier League	23	ProZone	1	1	1	0	0	0	1	1	1	6
Garvican (2013)	Male Australian U20 National Team	12	GPS	1	0	1	0	1	0	1	1	1	6
Hewitt (2014)	Australian Women’s National Team	15 (58)	GPS	1	1	1	1	1	0	1	1	1	8
Hoppe (2015)	Male German Bundesliga	N.S.	Vis.Track	1	0	1	0	0	0	0	1	1	4
Lago (2010)	Male Spanish Premier League	19 (182)	Amisco	1	1	1	1	1	0	1	1	1	8
Lago (2011)	Male Spanish Premier League	23 (172)	Amisco	1	1	1	1	0	1	2	1	1	9
Mohr (2010)	Male Spanish Second and Third Divisions	20	Amisco	1	0	1	1	1	0	1	1	1	7
Nassis (2013)	Fifa Men’s World Cup	N.S.		1	1	1	0	1	0	0	1	1	6
Nassis (2015)	Fifa Men’s World Cup	N.S.		1	0	1	0	0	0	0	1	1	4
Ozgunen (2010)	Male Semi-Professional	11 (19)	GPS Watch	1	0	1	1	0	0	0	1	1	5
Rampinini (2007)	Male European National League	20	ProZone	1	0	1	0	0	1	1	1	1	6
Rampinini (2009)	Male Italian Serie A	186	SICS	1	0	1	0	0	0	1	1	1	5
Redwood-Brown (2012)	Male English Premier League	(169)	ProZone	1	0	1	1	1	1	0	1	1	7
Rey (2010)	Male Spanish Premier League	42 (84)	Amisco	1	0	1	1	1	0	1	1	1	7

N.S. = not stated within the article cited.

Outcome measures

Technology

Before indicating the outcome measures of importance, it must be noted that it is difficult to compare data from a variety of technological sources (e.g. GPS and Prozone®). For example, total distance covered during a game has been reported to be greater (7%) using GPS as compared to using Prozone® [3]. However, greater distances for sprinting and high intensity running than GPS (70 and 16%, respectively) at the same speed thresholds were reported for Prozone®. Furthermore, GPS is subject to intra-unit (same manufacturer) variation and between manufacturer variations. Therefore, caution should be applied when comparing or interchangeably using data from GPS or Prozone® / Amisco Pro® technology, with players advised to wear the same GPS unit, from the same brand, to minimize inter-unit / manufacturer variability affecting data [85]. Effects presented in this review were observed as within study changes using the same technology, removing possible technological error.

Match activity

Match-running has been analysed, using a range of different movement categories including total distances and distance covered within specific speed thresholds (such as moderate-speed, high-speed and sprinting) [43, 86]. The frequency or occurrences of accelerations and high-speed or sprinting efforts have also been reported by some researchers [11, 38]. Distance covered at high-speed alone may underestimate energy expenditure by 6-8% [26, 27, 87], whilst not accounting for acceleration.

Temperatures were defined as; cold (0-10˚C), moderate (10-20˚C), warm (20-30˚C) and hot (>30˚C), as classified in previous studies [13, 69]. Recently there has been a shift to the use of wet bulb globe temperature to define heat stress, however, this was only used by one study included in this review [40].

Altitude was defined as; near sea-level (0-500 m), low altitude (500-2000 m), moderate altitude (2000-3000 m) and high altitude (3000-5500 m) as previously classified [88]. A congested schedule was defined as when a player played in multiple matches within a seven-day period [71, 83].

Methodological considerations

While this review does not perform any statistical analysis, the authors feel statistical considerations should be made when analysing GPS data. To appropriately detect changes, researchers must account for match-to-match variation and device reliability. Population-specific match-to-match variation, represented by a coefficient of variation (CV), has been reported to vary by 19.8-37.1% for high-speed running and sprinting [89]. However, the interpretation of variation can be further complicated by different players, positions, different technologies and the lack of consensus on speed thresholds amongst researchers [17, 89]. If not accounted for within an appropriate statistical model, match-to-match variation should be reported to avoid misinterpretation of findings. Inter-unit GPS variability should also be considered, with CV ranging from 1.5-6.0% for running and sprinting activities in a linear and non-linear fashion with a 1–Hz sampling rate [90]. Inter-unit reliability for velocity whilst accelerating has improved with 10-Hz sampling rates, with CVs of 1.9-4.3% reported when accelerating from a range of constant velocities [91]. When examining factors affecting performance, it is crucial to take reliability into account to detect changes outside the standard inter-unit variability.

Discussion

Situational factors influencing match-running

Formation

The effect of different formations on match-running for both opposition and of multiple reference teams have been investigated in the English Premier League and French Ligue 1 (Table 4) [19, 20]. While cognizant that very few studies have investigated this metric, there seem to be no meaningful effects of formation on match-running, suggesting team formations have little to no impact on how a player moves globally throughout a match. The use of multiple reference teams also complicates interpreting the effect of formation on match-running [19]. Furthermore, the evolution of tactics within a game results in teams rarely staying in one formation for a full game [92], adapting to current match situations such as score line and opposition strategies [93]. These factors make examining the effect of team formations on match-running challenging [20]. Studies have tended to examine team formations using four defenders (e.g. 4-4-2, 4-5-1 or 4-3-3), possibly limiting the findings and subsequent implications. Different formations (e.g. 5-4-1 or 3-5-2) are likely to result in

Table 4: The effect of reference / opposing team formation on player movements (m ± SD) of male soccer players.

Author	Level	Games (# files / players)	Capture Method	Team	Thresholds	Formation			
						4-4-2	4-3-3	4-5-1	4-2-3-1
Bradley (2011)	English Premier League	20 (n/a / 153)	Prozone	Reference	Total distance	10697 ± 945	10786 ± 1041	10613 ± 1104	
					>14.4 km·h^{-1}	2633 ± 671	2649 ± 706	2585 ± 734	
					>19.8 km·h^{-1}	956 ± 302	924 ± 316	901 ± 305	
Carling (2011)[a]	French Ligue 1	45 (297 / 21)	Amisco Pro	Opposing	Total distance	10594 ± 681	10795 ± 624		10808 ± 661*
					14.4-19.7 km·h^{-1}	1577 ± 373	1630 ± 376		1608 ± 374
					>19.7 km·h^{-1}	704 ± 219	741 ± 236		721 ± 222

[a] Considered 4-3-3 and 4-5-1 as a dynamic, interchangeable, formation.* Significant difference compared to 4-4-2 ($p < 0.05$)

different positional changes in match-running. The effect of different formations on reference team match-running using a repeated measures analysis has also not been undertaken and provides a focus for future research. The effect of ball possession, both high/low and in/out of possession, on match-running may provide a better insight as to how match-running changes in relation to opposing team formations [12, 43, 94, 95].

The effect of possession on position specific demands

Globally, having either a high (51-66%) or low (34-50%) percentage of ball possession results in trivial differences in match-running (Table 5) [12, 94]. Positional changes are more apparent when examining performance with respect to being in or out of ball possession [43, 95]. Attacking players appear to cover greater high-speed running distance (71%) when the team is in possession compared to out of possession [43]. Whilst defenders cover greater high-speed running distance (156%) when out of possession compared to in possession. This may be explained by forwards attempting to create space for scoring opportunities when the team is in possession, whilst defenders are required to cover these movements and regain ball possession [43]. For instance, players from a high percentage ball possession team were found spending more time in the opposition half and attacking third to create goal scoring opportunities [94], probably requiring forwards to move off the ball and defenders tracking them. Furthermore, match-running changes as a team were observed whilst in or out of possession against different opposition playing formations [19]. Very high-speed running was 32-39% ($P < 0.01$) greater when in possession against a 4-4-2 compared to a 4-5-1, however, total distance was similar against all formations [19]. Authors noted the inherent attacking and defensive characteristics of different formations as a possible reason for the changes they observed [19]. Due to the lack of repeated measures designs, the effect of ball possession and formation are still largely unclear.

The effect of score-line on match-running

An evolving factor, such as score-line, can also alter the work-rate of players [15, 42]. It was suggested that in the hope of getting back into the game, very high-speed running increased (11.3%) when Spanish Premier League teams were losing a match compared to winning when either total or effective playing time (i.e. total time minus stoppages) was considered [42]. Lago, Casais [70] also demonstrated that for every minute losing, an extra 1-m of distance was covered at sprint speeds (>19.1 $km \cdot h^{-1}$) compared to winning. Alternatively, winning increased low-speed movement (<11 $km \cdot h^{-1}$) by 2-m compared to losing. This finding, in particular, supports the suggestion that players do not always use their maximal physical capacity for an entire game [70]. Further, Redwood-Brown, O'Donoghue [15] observed a greater percentage of time spent at >14.4 $km \cdot h^{-1}$ was completed by attackers in the English Premier League when winning a game (1.3%), whilst defenders performed less (-0.7%). Further analysis is needed to better understand the role of score-line on match-running. Losing has been observed to increase possession in comparison to winning (11%) [96], however, pass accuracy of losing teams has been observed to be lower compared to the winning teams [97]. The inclusion of technical information and team success would, therefore, appear important when examining the match-running profile of reference teams.

Team success

The effect of opposition ranking on high-speed (Table 6), very high-speed and sprinting profiles has recently received attention [14, 36, 42-44, 81]. Total match-running alone does not relate to winning games, but Hoppe, Slomka [81] reported total distance in ball possession as the strongest predictor of point accumulation across a season. Players from more successful teams had greater ball involvement, with greater total distance and high-speed running performed whilst in possession. However, less successful teams have been reported to cover greater high- and very high-speed running distance compared to more successful teams in the Italian Serie A [14]. Also, teams who finished in the bottom five of the English Premier League were observed to cover more distance at high- (3.8%) and sprint-speeds (5.4%) compared to those in the top 5 [43]. Greater movement whilst in possession, to create space and maintain possession, therefore, might characterize success.

Researchers found after quantifying match-running performance of a highly ranked European reference team [44], that their match-running was greater against more successful teams. Additionally, both technical and physical performance may be at their greatest against similarly ranked opponents' due to a greater perceived chance of winning [42, 97]. Alternatively, players from a reference team performed greater high-speed running against similarly ranked opponents (11-25 in the world rankings; 17%), compared to playing against teams ranked within the top 10 of FIFA's Women's World Rankings [36]. Less successful teams may play a more defensive style against higher ranked teams, increasing the player

Table 5: The effect of high/low and in/out of possession on player movements (m ± SD) of male soccer players.

Author	Level	Games (# files / players)	Capture Method	Positions	Thresholds	High / In Possession	Low / Out of Possession
Bradley (2014)[a]	English Premier League	54 (/ 810)	Prozone	Central Defenders	Total distance	9739 ± 525	9943 ± 567
					14.4-19.7 km·h^{-1}	1270 ± 209	1375 ± 228
					19.8-25.1 km·h^{-1}	451 ± 104	480 ± 115
					>25.1 km·h^{-1}	153 ± 70	159 ± 61
				Fullbacks	Total distance	10610 ± 623	10856 ± 614
					14.4-19.7 km·h^{-1}	1702 ± 271	1777 ± 243
					19.8-25.1 km·h^{-1}	701 ± 174	748 ± 169
					>25.1 km·h^{-1}	275 ± 104	300 ± 113
				Central Midfielders	Total distance	11458 ± 625	11457 ± 726
					14.4-19.7 km·h^{-1}	2069 ± 334	2000 ± 330
					19.8-25.1 km·h^{-1}	764 ± 178	699 ± 194
					>25.1 km·h^{-1}	226 ± 95	207 ± 88
				Wide Midfielders	Total distance	11669 ± 828	11489 ± 859
					14.4-19.7 km·h^{-1}	2118 ± 412	1977 ± 413
					19.8-25.1 km·h^{-1}	884 ± 182	885 ± 173
					>25.1 km·h^{-1}	326 ± 119	341 ± 106
				Attackers	Total distance	10778 ± 865	9988 ± 1002
					14.4-19.7 km·h^{-1}	1685 ± 422	1422 ± 344
					19.8-25.1 km·h^{-1}	783 ± 198	682 ± 173
					>25.1 km·h^{-1}	317 ± 114	30 ± 125
Da Mota (2016)[a, c]				Forwards	Total distance	10011 ± 1042	10405 ± 1011
					≤11 km·h^{-1}	6016 ± 426	6158 ± 426
					11-14 km·h^{-1}	1611 ± 347	1832 ± 347
					>14 km·h^{-1}	2842 ± 474	3000 ± 474
				Midfielders	Total distance	10776 ± 845	10919 ± 861
					≤11 km·h^{-1}	6121 ± 383	6169 ± 271

					11-14 km·h^{-1}	2009 ± 335	2056 ± 319
					>14 km·h^{-1}	3092 ± 558	3156 ± 606
				Defenders	Total distance	9850 ± 853	9930 ± 692
					≤11 km·h^{-1}	6116 ± 274	6180 ± 306
					11-14 km·h^{-1}	1738 ± 241	1803 ± 241
					>14 km·h^{-1}	2543 ± 515	2543 ± 515
Dellal (2011)[b]	EPL and La Liga,	600 (5938)	Amisco Pro	Defensive	Total distance (in / out of possession)	10890 ± 417	
					21-24 km·h^{-1}	95 ± 32	158 ± 11
					>24.1 km·h^{-1}	92 ± 32	127 ± 14
				Offensive	Total distance (in / out of possession)	11098 ± 382	
					21-24 km·h^{-1}	164 ± 15	123 ± 31
					>24.1 km·h^{-1}	155 ± 26	90 ± 22
Di Salvo (2009)[b]	EPL	(7355 / 563)		Central Defenders	>19.8 km·h^{-1}	179 ± 93	459 ± 74
				Wide Defenders	>19.8 km·h^{-1}	364 ± 89	498 ± 71
				Central Midfielders	>19.8 km·h^{-1}	394 ± 91	489 ± 71
				Wide Midfielders	>19.8 km·h^{-1}	505 ± 76	484 ± 62
				Attackers	>19.8 km·h^{-1}	566 ± 104	331 ± 83

[a] Compared high and low possession. [b] Compared in and out of possession. [c] Data was extrapolated from figures.

Table 6: The influence of team success and opposition rankings on distance covered at high-intensities (m ± SD)

Author	Level	Games (# Files / players)	Capture method	Opposition / Reference Quality	Threshold	Distance
Castellano (2011)	Spanish Premier League	(/ 434)	Amisco Pro	Top 6	17.1-21.0 $km \cdot h^{-1}$	417 ± 143
					21.1-24.0 $km \cdot h^{-1}$	144 ± 59
					>24 $km \cdot h^{-1}$	115 ± 72
				Middle 7	17.1-21.0 $km \cdot h^{-1}$	411 ± 135
					21.1-24.0 $km \cdot h^{-1}$	137 ± 57
					>24 $km \cdot h^{-1}$	117 ± 75
				Bottom 7	17.1-21.0 $km \cdot h^{-1}$	386 ± 124
					21.1-24.0 $km \cdot h^{-1}$	128 ± 61
					>24 $km \cdot h^{-1}$	103 ± 72
Di Salvo (2009)	English Premier League		Prozone	Top 5	>19.8 $km \cdot h^{-1}$	885 ± 113
					>25.2 $km \cdot h^{-1}$	222 ± 41
				Middle 10	>19.8 $km \cdot h^{-1}$	917 ± 143
					>25.2 $km \cdot h^{-1}$	230 ± 51
				Bottom 5	>19.8 $km \cdot h^{-1}$	919 ± 128
					>25.2 $km \cdot h^{-1}$	234 ± 53
Hewitt (2014)[a]	Elite female soccer	13 (58 / 15)	GPS	Group A (1-10)[b]	6-12 $km \cdot h^{-1}$	1625
					12-19 $km \cdot h^{-1}$	2950
					% >19 $km \cdot h^{-1}$	3.5
				Group B (11-25)[b]	6-12 $km \cdot h^{-1}$	1475
					12-19 $km \cdot h^{-1}$	3450
					% >19 $km \cdot h^{-1}$	4.2
				Group C (25+)[b]	6-12 $km \cdot h^{-1}$	1550 ± 25
					12-19 $km \cdot h^{-1}$	3250 ± 50
					% >19 $km \cdot h^{-1}$	3.6 ± 0.3

Rampinini (2007)	“Major” European League and Champions League	34 (/ 20)		Best (Champions League or Top 8 in National League)	Total distance >14.4 km·h^{-1} >19.8 km·h^{-1}	11097 ± 778 2770 ± 528 902 ± 237
				Worst (Bottom 12 of National League)	Total distance >14.4 km·h^{-1} >19.8 km·h^{-1}	10827 ± 760 2630 ± 536* 883 ± 268*
Rampinini (2009)	Italian Serie A	416 (327 / 186)	SICS	Successful (1-5 final ranking)	Total distance >14 km·h^{-1} >19 km·h^{-1}	11647 3787 1196
				Less successful (15-20 final ranking)	Total distance >14 km·h^{-1} >19 km·h^{-1}	12190 4263 1309

[a] Data extrapolated from figures. [b] Based on FIFA Women’s World Rankings. * Significantly lower than best group $p<0.05$.

density within their defensive half to minimize attacking threats and opportunities (shots and crosses), impacting movement at higher speeds [36]. However, the findings of Hewitt, Norton [36] are limited due to a very small sample available (n = 15, files = 58). Therefore, further examination of the influence of team success on match-running is required to better understand player performance against higher or lower ranked opposition, with particular attention to playing style. In addition, with respect to physical performance against similarly ranked teams, researchers should look to characterize their reference team success to improve interpretation of findings presented.

Congested schedule

Many top European Club teams are required to cope with periods of congestion [35, 45, 46, 72, 84], although the extent to which players are exposed to these congested periods has been questioned recently [47]. However, it appears appropriate to examine how match-running is affected during these periods, with consideration to international soccer tournaments (such as the Olympics, Women's Algarve and Cyprus Cup) where recovery periods are ~72 hours throughout the group stage. Peak sprint speed, hamstring strength, and countermovement jump height are understood to be compromised for up to 72 hours post-match [30], indicating changes in performance could occur. A recent opinion article highlighted the current issues with research protocols for examining congested schedules [84], therefore, the current review only provides a brief overview of current knowledge which should be interpreted with caution. Examination of Spanish first division players who played two matches in a week, observed as mean distance covered across two games, with small changes in match-running observed (-8 to 1%, P = 0.12-0.96) when compared to one match per week [72]. A weekly mean was presented, with match-to-match changes not presented when two games were played in a week, severely limiting the findings and generalizability of this study. Furthermore, examination of half to half changes has resulted in no statistical differences in total distance or high-speed running distance during the second match in comparison to the first [83]. The major limitations of current literature assessing congested schedules are the small number of files available for analysis (n = 172 and 42, respectively). Although changes do not appear meaningful, injury rates and time loss from these injuries have been shown to increase in game two of a congested schedule, compared to game one [35, 46].

Although common match-running variables appear unaffected, alternative variables might be more sensitive to a period of match congestion [71]. An examination of youth soccer players who played five games, shortened in length, over three days reported a decrease in accelerations (-34%) [71]. It has been suggested that acceleration data should be examined through periods of congestion given its association with neuromuscular fatigue [30, 84]. A decreased rate of power development, due to neuromuscular fatigue, has also shown a small meaningful change (ES = -0.25) at 72 hours post fatiguing exercise during a jump analysis [98]. Therefore, it is plausible that accelerations could be affected for greater than 72-hours post-match. However, GPS is associated with high match-to-match variation (18%) when quantifying the number maximal accelerations [99]. This could limit the utility of acceleration as a measure for making informed decisions with absolute certainty, based on the possible large change required. Further analysis is required to determine the effect of a congested match schedule (<72 hours) on accelerations utilizing more robust study designs [84]. Researchers should also look to better define congested schedules as successive matches, with players, rather than teams, involved in multiple games. This is important to properly identify the changes that might occur.

Environmental factors

The effect of temperature on match-running

Soccer is played in a wide variety of environments (Table 7), with temperature being a consistent factor that may affect match outcome. For instance, the likelihood of a visiting team winning in the Gulf Region decreases by 3% for every 1°C increase in temperature as compared to home baseline conditions [100]. The home team might have been more acclimatized to the heat. Playing in the heat increases sweat rate and peripheral vasodilation in an attempt to dissipate heat, which can result in dehydration and competition between metabolic demands and heat loss requirements [101, 102]. These acute requirements can be offset by heat acclimation, with increased plasma volume and sweat rates to facilitate cooling to attenuate the rise in core temperature and heart rate [103] However, it remains unknown if the match outcome was influenced by a reduced match-running for the away team compared to the home team.. Recent research has observed declines in match-running in temperatures greater than 21°C [13], with French Ligue 1 midfielders completing 4% less total distance. Furthermore, total distance and high-speed running decreased (7 and 26%

respectively) whilst playing in the heat (43°C) compared to control conditions (21°C) in elite Scandinavian soccer players [104]. The non-randomised controlled design used by Mohr, Nybo [104] make the application of these findings to a larger population challenging.

A decrease (-2.4%, $P < 0.001$) in the percentage of total distance covered at low to moderate-speed running speed has been observed when playing at 41°C compared to 35°C [27]. An analysis of the 2014 FIFA World Cup Brazil [40] noted that high-speed activity was also decreased in matches played under high heat stress (8.5%, $p=0.020$), classified using wet bulb globe temperature. This decrease in high-speed actions was suggested to allow players to maintain a similar rate of successful passes (3%), with a similar number of passes performed, under high heat stress compared to low heat stress. Perception may account for the change of performance, with subconscious changes in movement patterns in response to thermal comfort [82, 103, 105, 106] and players may subconsciously also modify movement patterns to preserve technical actions [40]. Additionally, Link and Weber [107] reported players in the 1. Bundesliga reduced their total distance when playing in the heat, whilst preserving their ability to perform high-speed actions when required. Future analyses are advised to include technical data, where possible, to identify if changes in match-running are to preserve technical ability, whilst also including all match-running thresholds for analysis. Further inclusion of player hydration status and core temperature may provide a better understanding with regards to the effect of these physiological markers on match-running in the heat.

The effect of altitude on match-running

The effects of altitude on match-running are presented in Table 7. High-speed activity and accelerations (9-25% decrease) appear to be most susceptible to changes when matches at an altitude between 1600 m and 3600 m are examined in comparison to sea-level [11, 38, 41]. Despite the fact that altitude facilitates high-speed running, due to a decrease in the partial pressure of oxygen [108], negative changes occur due to a decrement in the production of ATP at altitude. A slowing of ATP re-synthesis following fatiguing exercise has been observed in hypoxic conditions [109], possibly limiting high-speed efforts, especially during short recovery periods [110]. Total distance covered at the 2010 FIFA World Cup in South Africa was also reduced (-2%, $P < 0.05$) above 1200-m [39]. However, given the small sample sizes and limited games analysed by previous research [11, 38, 41], application of

Table 7: The effect of temperature and altitude on distance covered, heart rate (Bpm) and physiological markers.

Author	Level	Games (# files / players)	Capture Method	Environment	Team (where relevant)	Variables	Control	Environmental Change
Aughey (2013)	Australian and Bolivian male age group national teams.	4 (122 / 27)	GPS	Sea-level vs Altitude (3600m)	Australia	Total distance	~92 m·min^{-1}	~9.8% ↓
						0.0-14.9 km·h^{-1}	~79 m·min^{-1}	~3.8% ↓
						15.0-36.0 km·h^{-1}	~12 m·min^{-1}	~25.0% ↓
						>10.0 km·h^{-2}	~2.2 accel·min	~4.3% ↓
					Bolivia	Total distance	~100 m·min^{-1}	~9.0% ↓
						0.0-14.9 km·h^{-1}	~80 m·min^{-1}	~12.5% ↓
						15.0-36.0 km·h^{-1}	~14 m·min^{-1}	~7.1% ↓
						>10.0 km·h^{-2}	~2.0 accel·min	5.0% ↑
Bohner (2015)	NCAA Women's soccer players	3 (18 / 6)	GPS	Sea-level vs Altitude (1839m)		Total distance	~120 m·min^{-1}	~10.0% ↓
						>13.0 km·h^{-1}	~27 m·min^{-1}	~7.4% ↓
						>13.0 km·h^{-1} %	10.4 %	1.3 % ↓
Carling (2011)	Elite male soccer players.	80 (339 / 9)	Amisco Pro	11-20˚C and >21˚C		Total distance	123.4 m·min^{-1}	3.8% ↓
						14.4-19.7 km·h^{-1}	21.3 m·min^{-1}	15.0% ↓
						>19.8 km·h^{-1}	8.2 m·min^{-1}	8.5% ↓
						First half >19.8 km·h^{-1}	8.1 m·min^{-1}	9.5% ↓
						Second half >19.8 km·h^{-1}	8.3 m·min^{-1}	8.4% ↓
Garvican (2013)	Australian male age group national team.	3 (36 / 12)	GPS	Sea-level vs Altitude (1600m).		Total distance	~114 m·min^{-1}	~9.6% ↓
						0.0-14.9 km·h^{-1}	~98 m·min^{-1}	~8.2% ↓
						15.0-36.0 km·h^{-1}	~16 m·min^{-1}	~18.8% ↓
						>10.0 km·h^{-2}	~2.9 accel·min	~3.4% ↓
Mohr (2010)	Elite male soccer players.	2 (34 / 17)	Amisco Pro	21˚C and 43˚C		Average / peak heart rate	160 / 183 Bpm	1.3% ↓ / 1.1% ↑
						First / second half core temperature	38.7 / 38.3˚C	2.3% ↑ / 3.4% ↑
						Post-match plasma lactate	3.3 mmol.L	48.5% ↑
						Total distance	~ 10100 m	7.0% ↓
						>14 km·h^{-1}	~2250 m	26.0% ↓
Özgunen (2010)	Semi-professional male soccer players	2 (15 / 11)	GPS	Heat index 35˚C and 41˚C		14.6-19.5 km·h^{-1}	934 ± 227 m	25.7% ↓
						19.6-25.5 km·h^{-1}	382 ± 99 m	12.6% ↓
						>25.6 km·h^{-1}	102 ± 44 m	5.9% ↑

inferences to larger populations is challenging. Furthermore, these studies were subject to different conditions, such as non-regulation match-lengths [38], coach instructions to play conservatively [11] and inappropriate player inclusion criteria [41] amongst others. The study of Nassis [39] was also limited as only total distance was analysed and summed for each team, therefore, not accounting for the match-running metrics most sensitive to environmental conditions or positional differences identified in this review. Findings would suggest that analysis of high-speed and acceleration metrics should be included in future studies due to their sensitivity to playing at altitude.

Conclusion

From the studies reviewed, it would appear that environmental factors play a strong role in the variability and differences observed in the match-running of soccer players. Caution, however, needs to be exercised due to the limitations of the studies presented, such as small sample sizes and minimal control. Alternatively, the proposed situational factors that may affect performance showed trivial to small changes, which were often within the match-to-match variation typically observed on a global level (full match). Further research is required to fully examine factors deemed to have a meaningful impact on performance, utilizing repeated measure designs to better identify any changes that occur within player, with a particular focus on youth a women's soccer required.

Recommendations

It is recommended that researchers identify within-player match-to-match variability and assess changes within players. Changes are entirely individual based on a variety of factors (such as position, physiological capacity) and therefore the use of linear mixed modelling is suggested. Particularly when assessing environmental changes where some athletes may respond differently to their environment than others. This will improve the understanding of these factors, but also allow for stronger justifications to be made with respect to the changes observed. Eventually, interventions to mitigate these changes, such as heat acclimation, should be assessed against match-related data such as actual games, small-sided games or 11v11 scrimmages.

The physical implications of specific tactics should be profiled in realistic training situations to assess the possible effect during matches. Coding in-game tactical shifts from reference team and/or oppositions and ensuring changes in physical work rate may also provide more insight into the impact of specific factors. Finally, peak-periods should also be examined to identify the worst-case scenarios that players could encounter. The identification of these periods will be more informative for practitioners who should be preparing players for these scenarios. This will inform training to a greater extent, with particular relevance for small-sided games and high-intensity interval training and their combined use for conditioning purposes.

Table 8: Summary of key findings.

Factor	Key Finding
Formation	Teams rarely stay in one formation for an entire match, making this factor complicated to examine with certainty.
Possession	Whether in/out of possession may alter high-speed running magnitudes positionally, but global high / low possession percentage appears to have little effect.
Score-line	Positional high-speed running differences exist in response to score-line, with attackers more active when winning and vice versa for defenders.
Team success	Varying findings have been presented, with similarly ranked teams likely to produce greater match-running performances. End of season rankings indicates greater total distance by less successful teams whilst greater high-speed running is performed in possession by more successful teams.
Congested schedule	Small changes in match-running have been identified, likely due to methodological issues in defining congested schedules.
Temperature	High-speed running distances decline in temperatures greater than 21°C. Total and low-speed running distances also decrease, possibly in an attempt to maintain high-speed actions.
Altitude	High-speed activity and maximal accelerations decline at altitudes >1600 m, likely due to physiological limitations in these environments.

Chapter 3: The match-to-match variation of match-running in elite female soccer

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Trewin J, 85%; Meylan C, 10%; Varley MC, 2.5%; Cronin J, 2.5%.

Prelude

From the review of the literature, a number of factors were identified which may affect the match-running of players. However, before these factors are examined, the match-to-match variation should be reported. Before data is reported to coaches, practitioners should be certain that changes in performance are outside that of what is considered normal. This is particularly important when reporting on changes in relation to players who might be underperforming compared to a normative match, or how a particular factor has affected performance. Although match-to-match variation has been examined in elite male soccer using semi-automatic camera systems, the match-to-match variation in elite female soccer has not been presented. Furthermore, this has not been analysed using global positioning systems, which are commonplace in elite team sports. Therefore, the purpose of this chapter was to examine the match-to-match variation of elite female soccer players during international soccer matches. The reported variation will provide a basis for examining the effects of selected match-factors in subsequent studies.

Introduction

The use of technology is now commonplace in the examination of match-running performance in team sports [3]. Both global positioning system (GPS) and semi-automated multi-camera systems (SAMCS) have been used, with each having advantages and disadvantages [3]. Recent law changes introduced by FIFA have allowed the use of GPS in official matches [111], allowing practitioners to utilise one system in both training and matches. This data has however been limited in the elite women's game with literature sparse [16, 31]. It is important to, therefore, understand the match-running occurring within women's matches. These law changes also bring into question the match-to-match variation using this technology and if subsequent inferences are meaningful or not, such as a change in match-running in response to an external factor (e.g. altitude or temperature). A biological variation occurs due to a number of factors, with differences in match situations and environments a likely cause [89]. Further, the reliability of devices to detect similar movement accurately can also affect the match-to-match variation observed. This is particularly problematic when movements with a high-rate of change are examined, where variation is known to increase [112]. Therefore, identification of the match-to-match variation must be taken into account when analysing match-running performances.

Previous studies in men's soccer have examined match-to-match variation [89, 113], with researchers reporting high-speed running to be the most inconsistent outcome variable of interest when measured with SAMCS (Coefficient of variation, CV = 18-20%). When the team is in ball possession, variation further increased (CV = 31-32%), with authors questioning the use of high-speed running as a performance indicator for soccer match performances. However, CV using GPS in women's soccer is relatively unknown, it is, therefore, essential to understanding the match-to-match variation of GPS metrics when attempting to justify with certainty changes in match-running in relation to match-factors, such as the environment or score-line.

Although this inherent variability exists, research has attempted to identify transient fatigue, the temporary reduction in match-running in response to a period of high-intensity [82]. Researchers examine peak-periods of match-running utilizing a pre-set time period (e.g. 5-min), to identify where match-running is at its greatest [16]. The fatigue profile of an athlete can help inform conditioning protocols and tactical decisions made by coaches within a match or matches. French Ligue 1 players performed 71-121 m of high-speed running during a peak period, using a pre-set 5-min period (e.g. 0-5, 5-10 mins), analysed using SAMCS [89], with high variation from match-to-match (CV = 24%). The ability to quantify a change in high-speed running from the peak- to post-periods indicated greater variation (CV = 134%), suggesting identification of transient fatigue is challenging. The assumption that a decline in match-running from peak to post periods is fatigue does not account for changes in tactical instructions or stoppages in play. Further, the use of pre-set time periods (e.g. 0-5, 5-10 mins, etc.) has also been questioned, with rolling periods shown to more accurately identify the peak-period of running by as much as 25% compared to pre-set periods [54]. However, to date match-to-match variation of this technique has not been examined and requires further research.

Lastly, with the ability to utilise GPS within official matches, this opens up the collection of data previously not possible, such as accelerations and manufacturer micro-sensor metrics. It has been suggested that examination of total distance alone, without accounting for accelerations or decelerations, may underestimate energy expenditure by 6-8% [26, 87]. Further, maximal accelerations have been observed to occur up to eight-fold more in matches than sprinting [28]. Micro-sensors can also be used when GPS satellites are not present, such as in enclosed stadia. This technology samples at a much greater rate and therefore may be more sensitive to changes in performance but also interference from noise [99]. Understanding the magnitude of variation with respect to these metrics is important when utilizing them in match analyses.

As match-running is of particular interest to practitioners, the quantification of match-to-match variation in an elite female population is of importance, particularly with respect to GPS systems. Researchers have suggested the use of a single reference team in the examination of match-to-match variation [89]. Therefore, the purpose of this study is to examine the match-to-match variation of elite female soccer players from a single national team during full international matches utilizing both a full match and a rolling 5-min analysis.

Methods

Elite female soccer players (n = 45) from the same senior national team ranked top 10 in the world, provided informed consent to participate in longitudinal tracking and data analysis which was approved by the University of Victoria Human Research Ethics Board. Player movement data was tracked across five years (2012-2016) and 55 International fixtures (Files

= 606). Only outfield players were included in the current study, with players belonging to the following positional groups, forward (FWD, n = 18); midfield (MF, n = 9); full back (FB, n = 11); and centre back (CB, n = 7). Where a player played in multiple positions, data in each position were analysed separately as two different players, due to the known positional differences in match-running.[95] Displacement and velocity data were collected from outfield players via GPS technology sampling at 10-Hz (Minimax S4, Catapult Innovations, Australia). Raw files were exported from manufacturer software (Sprint 5.1, Catapult Innovations, Australia) and analysed using a custom built MS Excel spreadsheet (2013, Microsoft, United States of America) [28]. Speed was calculated using the Doppler shift method, as opposed to the differentiation of positional data as the Doppler shift method is associated with a higher level of precision [114]. The average number of satellites and horizontal dilution of precision for games was 12.1 ± 0.4 and 0.94 ± 0.04 respectively.

Players were required to play a minimum of two 90-min match performances, with the analysed files ranging from of 2 to 21 games played per player (Mean ± SD = 7.0 ± 6.2. Data were only included from games played in “normative” conditions, considered as near sea-level (0-383 m) and in cold/mild temperature (5-19°C) (Files = 154). These criteria were used to mitigate the possible effects that some environmental factors may have on match-running performance [11, 13]. Two analyses were performed: a full match analysis; and a 5-min rolling analysis period, which was observed as a match maximum of both the peak ($Peak_5$) and the subsequent period after the peak ($Post_5$). The rolling analysis calculated movement in 5-min increments from each GPS time point, of which there were 10 per second [54].

Player movement categories were defined following locomotor analysis guidelines developed using elite male youth players, with thresholds set using pilot data of women’s players, which resulted in thresholds similar to that recommended in previous research [18, 24]. High-speed running was defined as an effort greater than 4.58 $m.s^{-1}$, which represented the mean maximal aerobic speed (MAS) of the team observed during piloting. Sprinting (Sprint) was defined as an effort exceeding 5.55 $m.s^{-1}$, a threshold representing the team average in the 30-15 intermittent fitness test [115] and is also close to the MAS plus 30% of the aerobic speed reserve (e.g. maximal sprinting speed minus MAS). This latter method has been used in previous literature to individualize maximal speed bands [24]. Maximal accelerations were defined as an effort greater than 2.26 $m.s^{-2}$, which represented 80% of a players acceleration over 10 m during a 40 m sprint test and was established during piloting. As a player may continue to accelerate at a submaximal rate following a maximal acceleration, an acceleration effort was defined as beginning when the acceleration exceeded the threshold of 2.26m.s^{-2} and finishing when the rate of acceleration dropped below 0 m.s^{-2} [28]. Acceleration was calculated from speed data over a 0.3 s time interval. Lastly, GPS was coupled with a 100 Hz accelerometer and used to estimate PlayerLoad™, an arbitrary value developed by the manufacturer to estimate total load experienced by the athlete [116]. Total distance, high-speed running distance, and PlayerLoad were presented relative to total match time, or rolling period time (/min). The number of high-speed running-efforts, Sprint-efforts, and accelerations were presented as a count per minute of match-play. A minimum effort duration of 0.30s (i.e. dwell time) was applied to speed data (high-speed running and Sprints).

Data are presented as means ± SD where appropriate. The coefficient of variation (CV) and 90% confidence intervals were calculated after logarithmic transformation in MS Excel. Raw values were log transformed using a natural logarithm, allowing uniformity of error [117]. Further, as players did not play the same number of games, a weighted CV was calculated to account for player contribution to the variance [99]. The smallest worthwhile change (SWC) was calculated as 0.20 of the raw between-player SD, prior to log transformation. The SWC can be used to assess true differences in performance, observed as a change greater than the SWC [118].

Results

The match-to-match variation and SWC of full match analysis metrics are presented in Table 9 and Table 10. CV values ranged from 6.1% to 53%, the lowest CVs associated with the total distance (6.4-6.8%) and low-speed running (6.1-6.5%). High-speed movements were found to have the highest variation, as observed in high-speed running (33%) and Sprint-efforts (53%). The MF group were the least variable for both total distance (5.6-5.7%) and low-speed running (5.2-5.5%), compared to all other positions for both metrics (6.4-7.9% and 6.1-8.2%, respectively). The CB group indicated the greatest variation for all high-speed movements (40-65%) and accelerations (21-22%).

CV values during the rolling 5-minute analysis ranged from 7.2% to 143% for all players (Table 11). The $Peak_5$ values for all metrics were similar to that of the full game analysis, within plus or minus 3.2%. The $Post_5$ CV values increased for all metrics, principally due to reduced mean values. The most substantial increase in the CV value occurred in high-speed running/min during $Post_5$ compared to $Peak_5$: 143% versus 31% respectively. This was particularly noticeable for the CB group, where the $Post_5$ CV was 262%, compared to the $Peak_5$ of 44%.

Discussion

This study is the first to examine the match-to-match variability of match-running performance in elite female soccer players using GPS technology. This is also the first study to include findings on the use of 5-min rolling analysis periods and maximal accelerations within an elite female population. The major findings from the repeated measures analysis were: 1) compared to high-speed running and Sprints, the greater occurrence and lower variability of accelerations warrants addition within match analyses; 2) PlayerLoad/min may be used with relative certainty, however, only within player comparisons should be considered; 3) $Peak_5$ periods are no more variable than full match analyses, highlighting their ability to identify the period of greatest match-running; 4) $Post_5$ periods for all movements are substantially more variable than both peak periods and full match analysis, limiting their use in identifying within match transient fatigue.

Researchers have suggested a possible link exists between accelerations and decelerations and post-match neuromuscular fatigue and energy cost [26, 119], which suggest particular relevance of such metrics in match analysis. The lower variability observed with accelerations/min in this study (CV = 17%) compared to high-speed running-efforts and Sprint-efforts (CV = 34% and 56% respectively), contradicts the findings of previous research [120] and demonstrate its suitability to be tracked from match to match. Differences in analysis methods could result in the lower variation observed in the current study, such as the definition of when an acceleration starts and finishes. Acceleration/min may be more sensitive to worthwhile changes in performance, with a smaller SWC (3.8%), compared to higher-speed metrics (6.4-9.2%). However, researchers and practitioners are still advised to apply caution when using acceleration/min and interpreting training or match data. Practitioners should also be aware of how GPS systems are detecting and defining the start/stop of an acceleration (e.g. once a player stops accelerating or once they drop below the threshold) [28]. This point, in particular, may play an important role in the variation of

Table 9: Match-to-match variation full game analysis metrics by position and overall presented as Mean ± SD.

Positional Role		FB	CB	MF	FWD	Overall
Match observations		N = 24	N = 44	N = 56	N = 30	N = 154
Total distance (m.min^{-1})						
	Mean ± SD	110 ± 9.2	100 ± 7.3	115 ± 7.9	108 ± 10	108 ± 10
	CV (90% CI)	7.7 (6.1, 11)	7.2 (6.1, 8.9)	5.6 (4.8, 6.6)	7.9 (6.4, 10)	6.8 (6.2, 7.6)
	SWC	1.7%	1.5%	1.4%	1.9%	1.9%
Low-speed running (m.min^{-1})						
	Mean ± SD	98 ± 7.2	93 ± 6.6	104 ± 6.1	98 ± 8.4	99 ± 8.3
	CV (90% CI)	6.7 (5.3, 9.2)	6.6 (5.2, 7.6)	5.2 (4.5, 6.2)	8.2 (6.7, 11)	6.5 (5.9, 6.8)
	SWC	1.5%	1.4%	1.2%	1.7%	1.7%
High-speed running (m.min^{-1})						
	Mean ± SD	12.5 ± 3.3	6.9 ± 2.3	10.2 ± 3.5	10.8 ± 3.2	9.7 ± 3.7
	CV (90% CI)	31 (24, 42)	41 (34, 51)	31 (26, 36)	28 (23, 37)	33 (30, 37)
	SWC	5.3%	6.7%	6.9%	6.0%	7.5%
Accelerations (count.min^{-1})						
	Mean ± SD	1.95 ± 0.29	1.96 ± 0.35	1.65 ± 0.34	1.81 ± 0.28	1.82 ± 0.35
	CV (90% CI)	13 (10, 18)	22 (18, 27)	15 (13, 18)	13 (11, 17)	17 (15, 19)
	SWC	3.0%	3.5%	4.1%	3.1%	3.8%
High-speed running-efforts (count.min^{-1})						
	Mean ± SD	0.78 ± 0.17	0.46 ± 0.15	0.70 ± 0.20	0.70 ± 0.18	0.64 ± 0.21
	CV (90% CI)	27 (21, 37)	45 (38, 55)	26 (22, 31)	28 (23, 36)	32 (29, 36)
	SWC	4.3%	6.3%	5.6%	5.2%	6.5%
Sprint-efforts (count.min^{-1})						
	Mean ± SD	0.28 ± 0.10	0.14 ± 0.06	0.20 ± 0.09	0.26 ± 0.09	0.21 ± 0.10
	CV (90% CI)	49 (39, 68)	65 (55, 81)	54 (46, 64)	35 (29, 46)	53 (49, 60)
	SWC	6.9%	8.5%	9.1%	7.1%	9.4%
PlayerLoad (AU.min^{-1})						
	Mean ± SD	10.6 ± 1.5	10.3 ± 1.7	13.2 ± 2.5	10.6 ± 2.4	11.5 ± 2.5
	CV (90% CI)	9.1 (7.2, 13)	14 (12, 17)	12 (10, 14)	20 (16, 25)	14 (13, 16)
	SWC	2.9%	3.3%	3.8%	4.6%	4.5%

CV = Co-efficient of Variation; CI = Confidence Intervals; .min^{-1} = per minute of match-play; SWC = smallest worthwhile change as a percentage of the mean.

Table 10: Absolute mean ± SD and CV of full game match-running metrics.

Positional Role		FB	CB	MF	FWD	Overall
Match Observations		N = 24	N = 44	N = 56	N = 30	N = 154
Total distance (m)						
	Mean ± SD	10496 ± 822	9533 ± 650	10962 ± 750	10380 ± 893	10368 ± 952
	CV (90% CI)	6.8 (5.4, 9.4)	6.6 (5.6, 8.2)	5.7 (4.9, 6.8)	7.1 (5.8, 9.2)	6.4 (5.8, 7.1)
	SWC	1.6%	1.4%	1.4%	1.7%	1.8%
Low-speed running (m)						
	Mean ± SD	9304 ± 629	8872 ± 594	9990 ± 588	9343 ± 739	9437 ± 771
	CV (90% CI)	5.5 (4.4, 7.7)	6.1 (5.2, 7.6)	5.5 (4.8, 6.6)	7.6 (6.2, 9.9)	6.1 (5.6, 6.8)
	SWC	1.4%	1.3%	1.2%	1.6%	1.6%
High-speed running (m)						
	Mean ± SD	1191 ± 314	661 ± 221	973 ± 334	1037 ± 305	930 ± 348
	CV (90% CI)	30 (24, 42)	40 (34, 49)	30 (26, 36)	28 (23, 36)	33 (30, 36)
	SWC	5.3%	6.7%	6.9%	5.9%	7.5%
Accelerations (count)						
	Mean ± SD	185 ± 27	187 ± 33	158 ± 33	174 ± 27	174 ± 33
	CV (90% CI)	12 (9.5, 17)	21 (18, 26)	15 (13, 18)	13 (11, 17)	16 (15, 18)
	SWC	2.9%	3.5%	4.2%	3.1%	3.8%
High-speed running-efforts (count)						
	Mean ± SD	74 ± 16	44 ± 14	67 ± 19	67 ± 17	62 ± 20
	CV (90% CI)	27 (21, 37)	44 (37, 55)	25 (22, 30)	27 (22, 35)	32 (29, 35)
	SWC	4.3%	6.3%	5.6%	5.1%	6.5%
Sprint-efforts (count)						
	Mean ± SD	26 ± 9	14 ± 6	20 ± 9	25 ± 9	20 ± 9
	CV (90% CI)	49 (39, 68)	65 (54, 80)	53 (46, 65)	35 (28, 45)	53 (48, 59)
	SWC	6.9%	8.5%	9.2%	7.1%	9.4%
PlayerLoad (AU)						
	Mean ± SD	1007 ± 147	982 ± 159	1265 ± 237	1016 ± 226	1096 ± 239
	CV (90% CI)	8.5 (6.7, 12)	14 (11, 17)	12 (10, 14)	19 (16, 25)	14 (12, 15)
	SWC	2.9%	3.2%	3.7%	4.4%	4.4%

CV = Coefficient of Variation; CI = Confidence Intervals; SWC = smallest worthwhile change as a percentage of the mean.

accelerations.

To the author's knowledge, this is the first study to present the match-to-match variation of PlayerLoad in soccer match-play, however, a strong relationship has been observed between PlayerLoad and total distance (r = 0.70) [121]. Recently researchers of field hockey have reported the relationship between PlayerLoad and total distance in both training and match scenarios [116]. A strong relationship (r = 0.63-0.74) was observed in training for absolute and relative metrics but weakened during matches when examined relative to minutes played (r = 0.49). The strength of association was primarily different by position, with strikers showing the weakest relationship in both relative and absolute terms (r = 0.13-0.69) during matches [116]. Practitioners should be aware of the challenges associated with PlayerLoad, with accelerometer data sensitive to collisions, tackles and jump landings, which may affect the magnitude of such data [71]. With that, positional demands should be considered when interpreting data and between player comparisons avoided [85]. It would seem from this study that PlayerLoad/min could potentially be used interchangeably with total distance/min with relative confidence as a global individual load.

The most-novel aspect of this study was the examination of peak-periods of play, using a rolling 5-min analysis period. These periods were first introduced in an attempt to identify within match transient fatigue [73, 82]. The use of a rolling period has been shown to better observe the most intense period in a match, compared to using pre-set periods [91], however, researchers have yet to define the match-to-match variation using such an analysis. Utilising pre-set 5-min analysis periods, researchers observed $Peak_5$ of total high-speed running (>19.8 $km.h^{-1}$) to be more variable (CV = 24%) than the full-match analysis (CV = 20%) [89]. In this study the opposite was observed, the $Peak_5$ of high-speed running/min exhibiting slightly less variability than the full match-analysis, whilst acceleration/min and PlayerLoad/min were similar in variability. It would seem that $Peak_5$ may be a useful metric to identify worst-case scenarios to inform conditioning protocols [50]. However, the variation of $Peak_5$ values would appear specific to the population examined, with practitioners advised to determine population specific CVs. Such data could be used to identify peak periods of play with the aim of creating drills designed to replicate this intensity, to optimize athlete preparation and possibly minimize injury risk.

Greater uncertainty surrounds the use of the $Post_5$ metrics as a means to identify transient fatigue during soccer matches, considering the variability associated with this

Table 11: Match-to-match variation of $Peak_5$ and $Post_5$ running metrics by position and overall as Mean ± SD.

Positional Role		FB	CB	MF	FWD	Overall
Match Observations		N = 27	N = 43	N = 59	N = 32	N = 161
Total distance $Peak_5$						
	Absolute	718 ± 46	658 ± 49	732 ± 50	707 ± 61	704 ± 59
	$m.min^{-1}$	144 ± 9.1	132 ± 9.8	146 ± 9.9	141 ± 12	141 ± 12
	CV (90% CI)	6.8 (5.4, 9.4)	7.7 (6.5, 9.5)	7.1 (6.1, 8.5)	6.9 (5.6, 8.9)	7.2 (6.5, 8.0)
	SWC	1.3%	1.5%	1.4%	1.7%	1.7%
Total distance $Post_5$						
	Absolute	551 ± 88	498 ± 64	152 ± 21	543 ± 82	540 ± 84
	$m.min^{-1}$	110 ± 18	100 ± 13	113 ± 17	109 ± 16	108 ± 16
	CV (90% CI)	18 (14, 25)	14 (12, 17)	15 (13, 18)	15 (12, 19)	15 (14, 17)
	SWC	3.2%	2.6%	3.1%	3.0%	3.1%
High-speed running $Peak_5$						
	Absolute	153 ± 39	101 ± 45	126 ± 34	127 ± 31	123 ± 41
	$m.min^{-1}$	30.7 ± 7.9	20.1 ± 9.0	25.2 ± 6.7	25.4 ± 6.1	24.6 ± 8.2
	CV (90% CI)	28 (22, 38)	44 (37, 54)	25 (21, 29)	21 (18, 28)	31 (28, 34)
	SWC	5.1%	9.0%	5.3%	4.8%	6.7%
High-speed running $Post_5$						
	Absolute	48 ± 25	24 ± 19	43 ± 25	44 ± 22	38 ± 24
	$m.min^{-1}$	9.7 ± 4.9	4.8 ± 3.7	8.5 ± 5.0	8.7 ± 4.4	7.7 ± 4.9
	CV (90% CI)	64 (50, 88)	262 (221, 326)	113 (97, 136)	78 (64, 102)	143 (130, 159)
	SWC	10%	16%	12%	10%	13%
Acceleration $Peak_5$						
	Absolute	18 ± 2.7	17 ± 2.9	15 ± 2.6	17 ± 3.7	17 ± 3.2
	$count.min^{-1}$	3.58 ± 0.54	3.44 ± 0.59	2.99 ± 0.52	3.44 ± 0.74	3.30 ± 0.63
	CV (90% CI)	16 (12, 21)	21 (18, 26)	17 (14, 20)	21 (17, 27)	19 (17, 21)
	SWC	3.0%	3.4%	3.5%	4.3%	3.8%
Acceleration $Post_5$						
	Absolute	11 ± 2.1	11 ± 3.1	8.9 ± 2.7	9.9 ± 3.1	10 ± 2.9
	$count.min^{-1}$	2.18 ± 0.42	2.16 ± 0.63	1.79 ± 0.54	1.99 ± 0.62	2.00 ± 0.59
	CV (90% CI)	27 (21, 38)	37 (32, 46)	35 (30, 42)	34 (28, 45)	35 (28, 39)
	SWC	3.9%	5.8%	6.0%	6.3%	5.9%
PlayerLoad $Peak_5$						
	Absolute	71 ± 11	70 ± 11	87 ± 16	72 ± 16	77 ± 16
	$AU.min^{-1}$	14.1 ± 2.3	14.0 ± 2.1	17.5 ± 3.2	14.3 ± 3.2	15.3 ± 3.2
	CV (90% CI)	9.3 (7.3, 13)	13 (11, 16)	12 (11, 15)	20 (16, 25)	14 (13, 15)
	SWC	3.2%	3.0%	3.7%	4.5%	4.2%
PlayerLoad $Post_5$						
	Absolute	46 ± 18	51 ± 14	65 ± 16	52 ± 15	55 ± 17
	$AU.min^{-1}$	9.3 ± 3.5	10.1 ± 2.7	13.0 ± 3.3	10.4 ± 3.0	11.1 ± 3.4
	CV (90% CI)	19 (15, 25)	20 (16, 24)	26 (22, 31)	26 (22, 34)	23 (21, 26)
	SWC	7.6%	5.4%	5.0%	5.8%	6.2%

CV = Co-efficient of Variation; CI = Confidence Intervals; $Peak_5$ = Peak 5-min period; $Post_5$ = Post 5-min period; min^{-1} = per minute of match play; SWC = smallest worthwhile change as a percentage of the mean; AU = Arbitrary Units method, particularly high-speed running/min (CV = 133%, SWC = 12%). Researchers have reported changes in high-speed running (29-58%) from $Peak_5$ to $Post_5$ in female soccer [16, 31, 122]. However, the variability of the change between $Peak_5$ and $Post_5$ has been reported as high as 134% using pre-set periods [89]. Situational factors, such as tactics, score line, and stoppages [54], could explain the large variation observed. Further, the $Post_5$ period may not be the period of lowest intensity, with the Post5 higher than the mean for some metrics examined. These findings highlight the challenge of trying to examine transient fatigue using current analytic techniques. With the possibility that match situations might dictate longer or shorter periods of maximal work-rate, 5-mins may not be the optimal observational period [123]. Further research is required to refine the use of peak-period analyses and the diagnostic value of this measure.

The positional findings of the current study indicate the need to assess variability and changes within player. Whilst the larger spread of the CI suggests a larger data set is required to examine positional data. The high-speed running and Sprint-efforts of the CB group observed the greatest variation compared to all other positional groups (CV = 41-65%). Whereas, the total distance and low-speed running of the MF group indicated the least variable metric examined (CV = 5.2-5.6%). These findings are similar to recent male research, which found Sprint distance (>25.2 km/h) to be the most variable in CB (CV = 45-58%) compared to that of FB (CV = 22-31%) [89]. This data highlights the need to use advanced statistical methods to analyse variation and changes within player [124]. Practitioners should also be aware of analysing individual player variation when making inferences on player match performances.

The reader needs to be cognizant of a number of limitations when reading this study. Due to the nature of elite international soccer, only 55 games were played throughout a five-year period limiting the sample size of the current study. Within this time period, player physical capabilities may have changed, which may have increased individual variation from match-to-match, however, this was not examined in the current study with further investigation suggested. This limited data set may also influence the positional data and CI observed. With researchers and practitioners advised to assess the variation of their own data sets before making inferences. Further, situational and environmental factors are known to alter player performance [11, 13, 42], although extreme environmental data were excluded from this study in order to limit their effects, situational factors were not accounted for.

Future research should examine the effects of different factors on the variation of player match-running. The examination of multiple teams is also suggested, with positional variation reported to further highlight the need to distinguish by position rather than generalize by team. Finally, the results are only relevant to the team investigated, with practitioners advised to examine variation within their own team.

Conclusion

From the results of this study, it appears that the match-to-match variation of total distance is acceptable to quantify the external load of elite female soccer players. High-speed activities are susceptible to higher variation, reducing their use as indicators of performance, whilst accelerations should be included in match analyses to account for the most energetically demanding activities. The use of $Peak_5$ to identify worst-case scenarios, the most intense physical load, is suggested. Albeit the identification of transient fatigue using the $Post_5$ period should be avoided. Further, examination of micro-sensor technology, including relationships with GPS metrics, is suggested based on the variability of the measures observed. Practitioners are advised to examine the individual variance of their players where possible, to best make inferences on changes in match-running performances observed.

Practical applications

- Data presented is specific to the team examined and should not be generalized. Researchers should explore the CV of their reference team as results will likely differ, whilst interpretation of findings will also be strengthened. Researchers should look to examine a large sample of teams using mixed linear modelling to better generalize findings whilst accounting for within player variation.
- Monitoring of accelerations/min is more stable than that of high-speed running-efforts and Sprint-efforts during match play. The greater occurrence of accelerations warrants inclusion of such data by practitioners to better indicate total work/effort and energy consumption.
- Micro-sensor use appears a viable alternative when GPS technology is not available. A strong link has been indicated between PlayerLoad and total distance, however, practitioners should be aware of the sensitivity of PlayerLoad magnitude to a variety of other factors, such as collisions.

- Identification of $Peak_5$ match-running periods appears similar in variability to that of full match analyses. This method can help inform conditioning protocols to prepare players for the worst-case scenarios observed within a match.

Section 2: What is the effect of match-factors on match-running in elite female soccer?

Chapter 4: The effect of match-factors on the running performance of elite female soccer players

Chapter 5: Are peak match-running periods affected by match-factors in elite female soccer players?

Chapter 4: The effect of match-factors on the running performance of elite female soccer players.

This chapter comprises of the following paper prepared for The Journal of Strength and Conditioning Research.

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Author contributions:

Trewin J, 80%; Meylan C, 7.5%; Varley MC, 7.5%; Cronin J, 2.5%; Ling D, 2.5%.

Prelude

The examination of match-to-match variation in 90 min players was important to allow identification of true changes in match-running performance. It was found that low-speed and total distance may be the most stable metrics of interest, whilst high-speed actions were the most susceptible to high variation. Inclusion criteria were varied across studies, with typical match analysis papers restricting inclusion of players to full match or those who played a full half. Researchers examining congested schedules have often utilised players who complete >75 min which assists in providing a larger dataset. The use of GPS allows practitioners to quantify accelerations and utilise micro-sensor technology to measure PlayerLoad when GPS signals are not available. To date, no research has utilised these GPS and micro-sensor based metrics to examine changes with respect to different match-factors. This chapter will provide a global overview of the changes in match-running with respect to selected match-factors; altitude, temperature, match outcome, opposition rankings and congested schedules. The purpose of this study, therefore, was to examine the effect of match-factors on match-running in elite female soccer players.

Introduction

The growth of female soccer as a sport was evidenced by the 2015 Women's World Cup the first to include 24 teams. Furthermore, the female game is becoming increasingly professional, however, the understanding and research of the female game are limited compared to the male game. Previously, wearable technology could only be worn during friendly matches, but recent law changes have enabled the use of global positioning system (GPS) in competitive soccer matches [111], providing the means for a variety of factors, such as altitude, match-outcomes, and opposition rankings, that affect the movement profiles of athletes to be quantified [42, 70, 79]. Understanding the effects these factors have on performance, in addition to the natural variation of match-running metrics, is vital to analyse match-performances with certainty. Further, identifying if these factors affect female athletes differently to male athletes is of importance to improve training protocols.

Environmental challenges are ever present, with the 2010 and 2014 FIFA Men's World Cups played at high altitudes and in high temperatures [39, 40]. Total distance (~10%) and accelerations (~4%) were observed to decline at altitude (1600-3600 m), compared to sea-level, in elite male and female youth players [11, 38, 41]. Lower (15%) high-speed running has been observed in elite male soccer players at temperatures greater than 21°C, compared to less than 21°C [13]. Only one previous investigation has observed female National Collegiate Athletic Association soccer players whilst playing at altitude (1839 m), compared to sea-level, the researchers reporting a decrease in total (~-13%, $p<0.001$) and high-speed running (~-11%, $p=0.039$) distances [41]. Physiological differences in sex may exacerbate performance changes in response to environmental factors, such as thermoregulation and menstrual cycle changes in core temperature, and further research is needed to document the changes in match-running performance in response to the environment for female soccer players [48, 49].

Opposition ranking is a situational factor which has been investigated, however varying definitions make it difficult to compare data [14, 42-44]. Nonetheless, greater total distance (2.5%) and high-speed running distance (5.3-7.7%), in addition to greater high-speed running distance with the ball (1.2-19%), has been observed when playing more successful teams compared to less successful teams [14, 42-44]. Elite female soccer players were reported to cover the greatest match-running across all movement thresholds against similarly ranked opponents [36]. Reduced leg power production in females [125] may result in shorter passing ranges for females compared to males resulting in different tactical approaches and impacting match-running relative to the different opposition. World rankings determined over several years may also affect match-running differently compared to a single season observed in male soccer. This may be due to a larger pool of teams/players available to play, which may adjust the style of an opposition team.

With regards to analyses of match-outcomes in relation to in match-running, Spanish Premier League players were observed to cover greater high-speed (16%) and sprint distance (5.4%) in a loss, whilst in a win the distances run at low (5.6%) and moderate (9.1%) speeds were higher [42]. Additionally, a greater percentage of time spent in high-speed movement (1.3%, $p = 0.004$) was reported in English Premier League attackers whilst winning a match [15]. Considering these findings for the most part relating to the male game, it would make sense to examine female performances, where the differences in opposition quality and playing styles could result in different outcomes.

Lastly, researchers have considered the idea of a congested schedule affecting match-running due to small recovery periods between the first and subsequent matches, with often trivial findings being reported [45, 46]. These findings have been questioned within the elite male game, with less than 41% of players completing 90 minutes during back-to-back matches [47]. However, the elite female game can often require national teams to play tournaments where four games are played in eight days (such as the Cyprus and Algarve cups) or FIFA windows with two games played within a three-day period. Therefore, the possibility of players being exposed to back-to-back 90 minute games is more likely, the effects of which requiring investigation.

Previous studies have utilised male athletes to examine the effects of environmental and situational factors on the match-running performance of soccer players. However, a single international female team of elite players has never been utilised in a single study, which enables changes to be observed within player over repeated games i.e. repeated measures design. Therefore, the purpose of this study was to examine the effects of altitude, temperature, opposition ranking and match-outcomes on the match-running of elite female soccer players.

Methods

Match analysis and participant data

Elite female soccer players from the same senior national team (n = 45) provided informed consent to participate in longitudinal tracking and data analysis, which was approved by the University of Victoria Human Research Ethics Board. Player movement data was tracked across four years (2012-2015) and 47 International fixtures. Only outfield players were included in the current study, with players belonging to the following positional groups, forward (FWD, n = 18); midfield (MF, n = 9); full back (FB, n = 11); and centre back (CB, n = 7). Speed data were collected from players via GPS technology sampling at 10 Hz (Minimax S4, Catapult Innovations, Australia). The reliability and validity of 10 Hz devices to measure velocity (Co-efficient of Variation; CV = 3.1-8.3% Pearson Correlation = 0.94-0.97) distance (Typical Error = 1.3-11.5%, no significant difference to criterion) and reliability of micro-sensor metrics (CV = 1.9%) have been previously reported [91, 126, 127]. Only files from players completing a full game defined as >75 mins, were included in the analysis (Files = 606). This inclusion criterion was based on previous congested schedule research [35] as well as the perception that an extra 15 min of playing time will not have a large effect in match data when normalized to minutes played (Table 12). Raw files were exported from manufacturer software (Sprint 5.1, Catapult Innovations, Australia) and analysed using a custom built MS Excel spreadsheet (2013, Microsoft, United States of America), with speed calculated using the Doppler shift method, as opposed to the differentiation of positional data [28]. This method is associated with a higher level of precision [114]. The match-to-match variation of the outcome measures of interest has been reported previously using the same data set for 90-minute performances [128]. The mean number of satellites and horizontal dilution of precision for games were 11.9 ± 0.4 and 0.96 ± 0.05 respectively. The number of satellites and the horizontal dilution of precision provide an insight into the quality of the GPS data analysed [85].

Match-factors

The following match-factors were investigated and defined as such. Opposition ranking was defined as being higher or lower than the reference team at the time of the match, based on official FIFA Women's World Rankings [129], which are updated four times annually [124].

Match outcome was defined as being a win, draw or loss at the end of the game. Match congestion was defined as a player who played >75 mins and two games within 72 hours of

Table 12: Comparison of dataset between inclusion of players who played ≥75mins or those who played the full 90mins (mean ± SD) Cohen's d and 90% Confidence Intervals.

	Playing ≥75mins (Files = 277)	Playing ≥90mins (Files = 222)	*d* (90% CI)
Total distance ($m \cdot min^{-1}$)	107.5 ± 9.7	106.7 ± 9.7	0.08 (-0.07, 0.23)
Low-speed running ($m \cdot min^{-1}$)	97.8 ± 8.1	97.2 ± 8.2	0.06 (-0.08, 0.21)
High-speed running ($m \cdot min^{-1}$)	9.7 ± 3.3	9.5 ± 3.2	0.08 (-0.06, 0.23)
Accelerations ($Count \cdot min^{-1}$)	1.81 ± 0.38	1.79 ± 0.37	0.04 (-0.11, 0.18)
High-speed running efforts ($Count \cdot min^{-1}$)	0.64 ± 0.19	0.62 ± 0.19	0.08 (-0.07, 0.23)
Sprint efforts ($Count \cdot min^{-1}$)	0.21 ± 0.09	0.21 ± 0.09	0.07 (-0.08, 0.22)

Cohen's d thresholds: Trivial = 0.00-0.20; Small = 0.20-0.60; Moderate = 0.60-1.20; Large = >1.20.

each other (Games = 17) [35, 45]. Altitude was defined as near sea-level (Games = 40, ≤500 m) or at altitude (Games = 7, >500 m). Due to the low number of games at altitude, all games were grouped together with altitudes ranging from 671 m to 1356 m [88]. The temperature was defined as cold/mild (Games = 26, <21°C) and warm (Games = 21, ≥21°C) with warm temperatures ranging from 21°C to 32°C [13]. The temperature was collected via historical environmental data for the city and approximate kick-off time via an online database [130].

Movement categories

Player movement categories were defined following previously described locomotor analysis guidelines for male youth athletes and similar to that suggested for females in previous literature [18, 24]. High-speed running, was defined as an effort > 4.58 $m \cdot s^{-1}$, which represented the mean maximal aerobic speed (MAS) observed during piloting. This method has been utilised by researchers to determine speed thresholds [23, 24], with MAS determined using the Maximal Aerobic Speed Test, with the final completed level achieved considered as the athletes MAS [131]. Low-speed running was therefore defined as any movement covered at < 4.58 $m \cdot s^{-1}$. Sprinting was defined as an effort > 5.55 $m \cdot s^{-1}$, a threshold representing the team mean in the 30-15 intermittent fitness test and was also the MAS plus 30% of the aerobic speed reserve (e.g. maximal sprinting speed minus MAS). This latter method has been used in previously to individualize maximal speed bands [24]. Maximal accelerations were defined as an effort > 2.26 $m{\cdot}s^{-2}$, which represented 80% of players' acceleration over 10 m and was established during piloting. As a player may continue to accelerate at a submaximal rate following a maximal acceleration, an acceleration effort was defined as beginning when the acceleration exceeded the threshold of 2.26 $m{\cdot}s^{-2}$ and finishing when the acceleration dropped below 0 $m{\cdot}s^{-2}$ [28]. Acceleration was calculated from speed data with a 0.3 s smoothing filter. Total distance, high-speed running and sprint thresholds were presented relative to total match time ($\cdot min^{-1}$). The number of high-speed running-efforts, sprinting-efforts, and accelerations was presented as a count per minute of match-play. A minimum effort duration of 0.3 s was applied to all speed data (high-speed running and sprinting).

Statistical analysis

Due to the clustering of data, the effect of match-factors was examined using a negative binomial mixed model using STATA (v13, StataCorp, College Station, TX). Separate analyses were performed for all match activities, with each match factor as a fixed main effect. Match outcome and opposition ranking were analysed as an interaction term. Random effects for the player and for the match were included in the model to account for repeated measures.

An inference about the true value of a given effect was based on its uncertainty in relation to the important difference, assumed to be 0.20 of the standard deviation between players in a normal match. This was derived from the mixed model by adding the variance for the true differences between players with the match-to-match variance within players, before taking the square root. Inferences were non-clinical, with an effect deemed unclear if the 90% confidence interval (CI) included the smallest important positive and negative differences; otherwise, the effect was deemed clear. Chances of a greater or smaller substantial true difference were expressed quantitatively and calculated using a custom-made Excel spreadsheet [132]. These chances were expressed qualitatively for clear outcomes as follows: >25-75%, possibly; >75-95%, likely; >95-99%, very likely; >99%, almost certainly. The magnitude of a given effect was determined from its observed standardized value (the difference in means divided by the between-subject standard deviation). The magnitude was expressed qualitatively as follows: <0.20, Trivial; 0.20-0.59, Small; 0.60-1.19, Moderate; ≥1.20 Large [124].

Results

Descriptive data in relation to each match factor (Table 13) is presented prior to linear modelling.

Environmental factors

The standardised changes in metrics at altitude for all environmental factors can be observed in Figure 3. Compared to sea-level, total distance (-4.0%, CI: -5.9%, -2.1%; P = 0.001) and low-speed running (-4.0%, CI: -5.8%, -2.1%; P < 0.001) were very likely lower at altitude, with low-speed running (-2.2%, CI: -3.7%, -0.7%; P = 0.019) also likely lower in warm temperatures compared to cold or mild temperatures. Alternatively, the number of max accelerations were likely higher at altitude compared to sea-level (6.8%, CI: 2.0%, 12%; P = 0.023), however, were very likely lower in warm temperatures compared to cold or mild temperatures (-14%, CI: -20%, -7.3%; P < 0.001).

Situational factors

Playing higher ranked teams in a draw, compared to lower ranked teams, resulted in very likely lower high-speed running (-24%, CI: -40%, -8.4%; P = 0.015), likely lower accelerations (-10%, CI: -20%, 0.4%; P = 0.088), likely lower high-speed running-efforts (-19%, CI: -34%, -15%; P = 0.039) and very likely lower sprinting-efforts (-35%, CI: -55%, -15%; P = 0.006). Losses against higher ranked teams, compared to lower ranked teams, were associated with likely higher total distance (3.8%, CI: 1.3%, 6.4%; P = 0.014) and very likely higher low-speed running (4.4%, CI: 2.2%, 6.6%; P = 0.002). Wins against higher ranked teams, compared to lower ranked teams, were associated with very likely higher total distance (4.7%, CI: 2.2%, 7.2%; P = 0.003), very likely higher low-speed running (4.6%, CI: 2.5%, 6.8%; P = 0.001) and likely higher accelerations (9.5%, CI: 3.3%, 16%; P = 0.015).

Playing against a lower ranked team in a loss, compared to a draw, resulted in very likely lower accelerations (-15%, CI: -25%, -6.2%; P = 0.008) and likely lower low-speed running (-3.8%, CI: -7.3%, -0.3%; P = 0.079). Playing in a win, compared to a draw against

Table 13: Raw unadjusted descriptive data (mean ± SD) of match-running in relation to factors examined.

	Players (Files)	Total distance (m·min^{-1})	Low-speed running (m·min^{-1})	High-speed running (m·min^{-1})	Accelerations (Count·min^{-1})	High-speed running efforts (Count·min^{-1})	Sprint efforts (Count·min^{-1})
Environmental							
Sea-level (≤500 m)	30 (233)	108 ± 9.8[a]	98 ± 8.2	9.8 ± 3.3	1.80 ± 0.38[a]	0.64 ± 0.19	0.21 ± 0.10
Altitude (>500 m)	13 (44)	104 ± 7.8	95 ± 7.0	9.3 ± 2.9	1.85 ± 0.40	0.60 ± 0.17	0.21 ± 0.08
Cold/mild (<21°C)	28 (203)	108 ± 9.5[b]	98 ± 7.7	9.8 ± 3.4	1.84 ± 0.35[b]	0.65 ± 0.19	0.22 ± 0.10
Warm/hot (≥21°C)	20 (74)	106 ± 9.9	96 ± 8.9	9.5 ± 2.9	1.73 ± 0.44	0.60 ± 0.17	0.21 ± 0.09
Situational							
Win	26 (152)	108 ± 9.7	99 ± 7.9	9.5 ± 3.4	1.77 ± 0.36	0.63 ± 0.20	0.21 ± 0.10
Draw	16 (35)	104 ± 9.6	95 ± 8.5	9.2 ± 3.4	1.91 ± 0.45	0.58 ± 0.20	0.20 ± 0.11
Loss	22 (90)	107 ± 9.4	97 ± 8.0	10.3 ± 2.9	1.83 ± 0.38	0.67 ± 0.16	0.08 ± 0.23
Win vs higher ranked	16 (23)	111 ± 9.0[c]	101 ±7.8[c]	9.9 ± 3.1	1.81 ± 0.27	0.65 ± 0.18	0.22 ± 0.10
Draw vs higher ranked	13 (23)	104 ± 9.9	95 ± 8.2	8.2 ± 3.3	1.82 ± 0.47	0.53 ± 0.21	0.17 ± 0.11
Loss vs higher ranked	18 (64)	107 ± 10	97 ± 8.7	10.1 ± 2.8[c]	1.84 ± 0.39	0.66 ± 0.16[c]	0.22 ± 0.08[c]
Win vs lower ranked	25 (129)	108 ± 9.7	99 ± 7.9	9.4 ± 3.4[c]	1.76 ± 0.37[c]	0.63 ± 0.20	0.21 ± 0.10[c]
Draw vs lower ranked	11 (12)	105 ± 9.0	94 ± 8.9	11.1 ± 2.8	2.07 ± 0.35	0.67 ± 0.14	0.27 ± 0.07
Loss vs lower ranked	16 (26)	107 ± 7.7	96 ± 5.9	10.9 ± 3.0	1.80 ± 0.33[c]	0.69 ± 0.15	0.25 ± 0.08
>72 Hours	30 (211)	108 ± 9.5	98 ± 7.9	9.7 ± 3.0	1.79 ± 0.36	0.63 ± 0.16	0.21 ± 0.10
<72 Hours	14 (65)	107 ± 9.7	97 ± 8.2	10.0 ± 3.4	1.85 ± 0.39	0.65 ± 0.20	0.23 ± 0.09

Legend: [a] Different to altitude ($P < 0.05$), [b] Different to warm/hot ($P < 0.05$), [c] Different to a draw ($P < 0.05$).

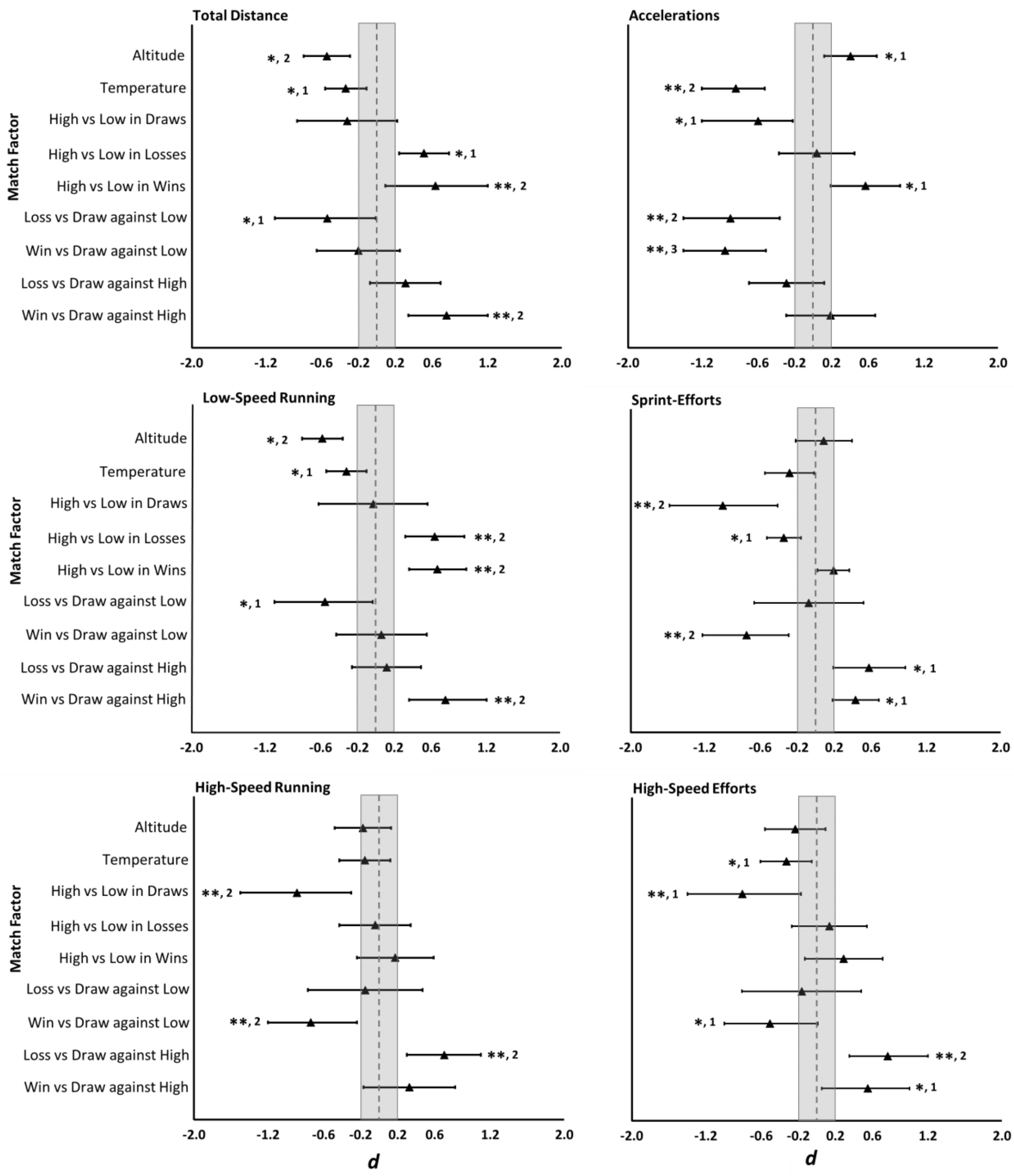

Figure 3: The change in match-running performance in relation to match-factors presented as Cohen's d (90% Confidence Limits). Symbol shown if likelihood also present. * = Small Change, ** = Moderate change, [1] = Likely Change, [2] = Very Likely Change, and [3] =Almost Certainly

the same opposition, resulted in almost certainly lower accelerations (-16%, CI: -24%, -8.8%; P = 0.001), very likely lower sprinting-efforts (-26%, CI: -43%, -9.5%; P = 0.012) and very likely lower high-speed running (-20%, CI: -34%, -6.7%; P = 0.017). Playing against a higher ranked team in a loss, compared to a draw, was associated with very likely higher high-speed running (19%, CI: 8.1%, 30%; P = 0.006), very likely higher high-speed running-efforts (18%, CI: 8.4%, 28%; P = 0.004) and likely higher sprinting-efforts (20%, CI: 5.0%, 34%; P = 0.030). Meanwhile a win against a higher ranked team, compared to a draw, resulted in very likely higher total distance (5.6%, CI: 2.5%, 8.6%; P = 0.004), very likely higher low-speed running (5.2%, CI: 2.5%, 7.9%; P = 0.003) and likely higher high-speed running-efforts (13%, CI: 1.2%, 25%; P = 0.071).

The analysis of the effects of a congested schedule provided no significant or meaningful findings for all outcome measures (P = 0.191-0.777).

Discussion

The purpose of this study was to examine the effects of environmental and situational factors on the match-running performance of elite female soccer players. This is the first study to examine such variables in a female population utilizing GPS technology. The major findings that were meaningful are: 1) overall match-running performance, particularly acceleration ability, was lower during higher temperatures (≥21°C) compared to lower temperatures; 2) when altitude is greater than 500 m, a greater number of accelerations and lower total distance and low-speed running distance were performed; 3) both higher and lower match-running performance was observed in relation to relative opposition ranking (higher or lower); 4) match-running was influenced by the opposition ranking and the interaction of match outcome which should be considered in future match analyses.

The effect of temperature on match-running performance in male soccer has been previously examined, with a decline in high-speed running shown in temperatures greater than 21°C [13]. In the current study, a moderate decrease in acceleration was observed in warm temperatures (mean = 26.5°C). It has been reported that acute performances in warm temperatures increase core temperature compared to cooler conditions, which results in increased competition between metabolic demands and heat loss requirements [101, 102]. These acute changes in core temperature may result in increased muscle temperatures, increasing the rate of glycogenolysis and lactate accumulation within muscle [133], influencing the ability of players to sustain repeated explosive efforts throughout a match. This is of particular importance for females who may be physiologically disadvantaged in the heat due to higher body fat and surface area-to-mass ratios compared to male counterparts in addition to hormonal changes due to the menstrual cycle [48]. It has been suggested that players may subconsciously adjust movement in an attempt to limit the rise of core temperature, muscle temperatures and maintain their ability to complete high-speed running actions in male soccer [107]. A small decrease in low-speed running may be indicative of this altered pacing strategy, however, confirmation of this is complex due to psychological and coach interactions. With a possibly trivial change in high-speed running observed in the current study, more data is required to improve the certainty of this change. With the nature of soccer, it is challenging to examine the exact physiological changes occurring, such as lactic acid accumulation and core temperature, with collection limited by the laws of the match. Researchers should look for alternative methods, such as thermal comfort ratings when analysing performances in the heat [106].

Altitude is known to inhibit endurance performance [88, 134, 135], whilst its effects on intermittent sports are becoming increasingly important to understand. The current findings indicate that a small increase in the number of accelerations occurred at altitude. Due to a decrease in the partial pressure of oxygen at altitude, it is easier to accelerate and obtain maximal speed [108], whilst, total distance and low-speed running may decrease to allow for recovery between acceleration efforts. Our findings differ to researchers who have reported a decline (3.4-4.3%) in acceleration at 1600-3600 m in youth male soccer players [11, 38], the findings attributed to a decreased ability to recover from repeated accelerations at altitude. With a mean altitude of 810 m in the current study, it may be plausible that with altitudes less than 1000 m, the decline in maximal aerobic power and blood oxygen saturation may not be sufficient enough to inhibit repeated acceleration performance [135]. It is important to note, that several factors could be responsible for these findings, such as match situations, tactical instructions or the speed thresholds and definitions utilised. Therefore, the findings of this study should be interpreted within this context, particularly if playing at higher altitudes. Physiological differences between sexes should also be considered, with further research required in both male and youth populations of both sexes.

Previous researchers have observed both physical and technical performances to be greatest against similarly ranked opponents in both male and female soccer, due to a greater perceived chance of winning [36, 42, 97]. From our findings, a moderate increase in high-speed running and a small increase in accelerations in a draw when playing lower ranked opponents was observed when compared to higher ranked opponents. Meanwhile, playing higher ranked opponents, compared to lower ranked opponents, a moderate increase in low-speed running was observed in both wins and losses in this study. Researchers have suggested that in an attempt to maintain player density in their defensive half against higher ranked opponents, lower ranked teams may increase lower speed movements to maintain shape [36]. In male soccer, higher percentage ball possession teams have been shown to spend greater time in the opposition half than lower percentage ball possession teams, which may be indicative of playing a higher ranked opponent [94]. Meanwhile, the small increase in accelerations observed against higher ranked teams in a win may suggest a pressing strategy was also employed by the team in the current study, with players looking to close-down opposition quickly to win the ball back. Further research is required to examine team tactics, such as a pressing strategy, with respect to match-running performance and opposition rankings. The inclusion of technical information, such as possession, the number of passes and pass accuracy may also help to characterize the reference team and its opponents [97, 136], aiding in the interpretation of findings.

In this study, match-outcome had an interactive effect with opposition rankings in the examination of match-running. Moderate increases in total distance and low-speed running were observed when playing higher ranked opponents in a win compared to a draw. However, the opposite was true against lower ranked opponents in a loss compared to a draw, with a small decrease in total distance and low-speed running observed. Further, a loss against higher ranked opponents resulted in a moderate increase in high-speed running and high-speed running-efforts, which coincided with a small increase in total distance. These findings are similar to the conclusions presented in previous research with male players, the authors suggesting that low-speed activity may decline when losing in an attempt to draw level with the opposition [70]. Whilst, scoring against a higher ranked opponent may increase the shared belief and overall effort of a team to achieve the desired outcome [15]. Therefore, the evolution of the score line rather than match outcome may provide a greater insight into the relationship between physical match demands and tactics.

A limitation of this study was that positional analysis was not possible, due to the limited number of repeated measures by position. It is understood that positional match-running requirements differ amongst players, therefore generalization of findings to all members of a team are not recommended, with practitioners advised to examine these factors within their own data. The size of the data set also limited the examination of interactions e.g. matches played against higher ranked opponents in hot conditions. This would have provided a greater insight into the changes these match-factors may have had on performance. Altitude in the current study can be considered as low, therefore, findings observed are likely to differ from those reported from higher altitudes. This is particularly noticeable with accelerations increasing contrary to previous studies [11, 38]. As this study was a retrospective design, the temperature was not collected accurately at the stadium for all matches. As historical temperature data was utilised, this may not provide correct values, therefore, we suggest future studies utilise thermometers and analyse temperature as close to kick-off as possible. Technical parameters, such as possession and pass accuracy, were not included in this study. Whilst accounting for the tactical approach of the team may also help to provide further insight in to some of the changes observed. Researchers have suggested that players may sub-consciously adjust match-running in an attempt to maintain technical proficiency [40]. Furthermore, match outcome may not be as insightful as the state of the game limiting the findings of this study also.

Conclusion

In summary, match-factors can influence the match-running of elite female soccer players. Total distance appears the most susceptible to different factors, whilst larger magnitude changes in acceleration are apparent in different environments and match-outcomes. Further examination of the interaction between opposition rankings and match-outcomes is warranted. Whilst practitioners and researchers should look to utilise advanced modelling techniques when examining how factors may affect match-running performance of their athletes by accounting for within player variation, allowing greater certainty in the findings observed. Finally, any difference in findings between this study and previous male research highlights the need for sex-specific research to be completed. Whilst some findings could be attributed to the playing style of the reference team, the examination of multiple teams would remove this bias in the future.

Practical recommendations

Practitioners are recommended to compile a database of match performances with the ability to adjust for a variety of conditions. This will allow for an understanding of changes which may occur, whilst also informing player selection, with the ability to profile player performances in response to these conditions. This may be used to inform technical staff on who may be better suited to different environmental conditions, or who can sustain a game-plan for longer periods against higher ranked opponents. Whilst the use of advanced statistical models, like that used in the current study, is recommended to assist in the identification of what factors affect their players to the greatest extent.

Further, knowing that some matches maybe be physically harder than others, practitioners can use this database to help guide recovery protocols post-match. The physical guidelines given to technical staff can also be adjusted based on the expected load of a given match in relation to the opposition ranking and match location. This is of importance when playing at altitude or in higher temperatures which are known to lower match-running performance, whilst possibly still being physiologically straining on the player.

Chapter 5: Are peak match-running periods affected by match-factors in elite female soccer players?

This chapter comprises the following paper submitted to the International Journal of Sports Physiology and Performance.

Reference: Trewin J, Meylan C, Chang-Tsai M, Varley MC, Cronin J. Are peak match-running periods affected by match-factors in elite female soccer players? Int J Sports Phys Perf. 2017: [In Review].

Author contributions:

Trewin J, 82.5%; Meylan C, 5%; Chang-Tsai M, 5%, Varley MC, 5%; Cronin J, 2.5%.

Prelude

In the previous chapter, it was found that match-factors affected the match-running of soccer players during a full game, with the most notable changes observed at higher altitudes and with higher temperatures. Meanwhile, interactions between a combination of match outcomes and opposition rankings were found to have varying effects, particularly on total distance and low-speed running. The peak match-running performed, or worst-case scenario, is an aspect of preparation gaining interest in research, with the understanding of the magnitude of these periods important for practitioners to prepare their athletes appropriately. Furthermore, identifying which combination of these factors produces the greatest peak period should assist practitioners in preparing players for the worst-case scenario they might experience. Analysis of peak match-running using predefined periods (such as 0-5, 5-10, 10-15 min) has been shown to underestimate total distance by as much as 25% compared to a rolling analysis period. Therefore, the purpose of this study was to utilise a rolling analysis to identify the effects of altitude, temperature, match-outcome and opposition rankings on the peak match-running of elite female soccer players.

Introduction

Increased exposure and growth of women's soccer has seen the game improve greatly, however, understanding of the current match-running of elite female soccer players is still limited in the literature [16, 36]. A comprehensive understanding of the movement profiles of elite players is required to better inform training prescription and programming [16]. Therefore, it is of importance that researchers and practitioners look to expand the literature in this area to provide practitioners with strong scientific evidence and rationale.

As with any outdoor sport, soccer is often subject to a variety of factors that may affect performance in a variety of ways. Researchers have shown that altitude (2400-3600 m) can decrease total distance travelled in a game, whilst high temperatures (>21°C) decreases distance covered at high-speeds [11, 13, 38]. Team success or opposition ranking have both shown variable changes in movement patterns [14, 36], whilst the evolution of the score-line or match-outcomes may also have an impact on performance [15, 70]. The majority of this research utilised data from male soccer, highlighting the lack of understanding how these factors influence the female game. Differences in sex physiology may exacerbate performance changes in response to environmental factors, such as thermoregulation and menstrual cycle changes in core temperature [48, 49]. Whilst different tactical approaches applied by female teams, in addition to a smaller pool of truly elite teams, may impact match-running relative to different opposition and match-outcomes [137].

General match analyses examine full match data, which provide the average movement demands of match-play. Recent researchers have suggested that current training prescription may not prepare players for the most intense periods of match-play, or worst-case scenario [9]. Including this type of training may help prevent soft-tissue injuries compared to if players are not prepared for these scenarios [9]. Therefore, it would be appropriate to examine peak running periods, which have generally been defined as a pre-set 5-min period (e.g. 0-5, 5-10, 10-15 mins and so on) of match-play [16, 89]. Researchers have reported an underestimation of the magnitude of the peak running period using this method, with the use of a rolling analysis suggested [54]. The use of a rolling analysis has so far not been examined in women's soccer, however, data from male youth indicate it is sensitive to environmental conditions [11, 38].

The lack of scientific evidence in female soccer highlights a major need for research in this area. Particularly, the effect of match-factors and the use of a rolling analysis to identify peak match-running periods are required. Therefore, the aim of this study was to examine the effect of different match-factors on the peak 5-min running performance of elite female soccer players utilizing a rolling analysis method.

Methods

Match analysis and participant data

Elite female soccer players from the same senior national team (n = 40) provided informed consent for longitudinal tracking and data analysis of playing performance to take place. The University of Victoria Human Research Ethics Board approved the study. Player movement data was tracked across five years (2012-2016), 55 International fixtures and 513 files (Files = 1-43 per player) were analysed. Only outfield players who had completed an entire match-half were included in the analysis, with players belonging to the following positional groups, forward (FWD, n = 20); midfield (MF, n = 10); fullback (FB, n = 11); and centre back (CB, n = 9). Velocity data were collected from outfield players via GPS technology sampling at 10 Hz (Minimax S4, Catapult Innovations, Australia). Raw files were exported from manufacturer software (Sprint 5.1, Catapult Innovations, Australia) and analysed using a custom-built MS Excel spreadsheet (2016, Microsoft, United States of America). Speed was calculated using the Doppler shift method, as opposed to the differentiation of positional data [28], as this method is associated with a higher level of precision [114]. Data were analysed during 5-mins intervals from every sampled time-point as distance covered or efforts completed, except when there was less than 5-mins remaining [54]. The peak period ($Peak_5$) was then identified and utilised for statistical analysis. The reliability of this method has been examined previously, with a coefficient of variation for distance (7.2%), high-speed running (31%), accelerations (19%) and PlayerLoad (14%) reported for $Peak_5$ periods [128]. The average number of satellites and horizontal dilution of precision for games were 12.0 ± 0.3 and 0.94 ± 0.04 respectively.

Match-factors

The effect of the following match-factors was observed in the current analysis. Opposition ranking was defined as being higher (Games = 20) or lower (Games = 35) than the reference team, based on official FIFA Women's World Rankings [129], at the time of the match [124]. Match outcome was defined as being a win (Games = 34), draw (Games = 5) or loss (Games

= 16) at the end of the game. Altitude was defined as near sea-level (Games = 49, ≤500 m) or at altitude (Games = 6, >500 m), due to the low number of games at altitude, all games were grouped together with altitudes ranging from 671 m to 1356 m [88]. Temperature was defined as cold/mild (Games = 41, <21°C) and warm (Games = 14, ≥21°C) with warm temperatures ranging from 21°C to 32°C (21-25°C = 6, 26-30°C = 6 and >30°C = 2) [13]. Temperature was collected retrospectively via online database for the city and approximate kick-off time [130].

Movement categories

Player movement categories were defined following previously described locomotor analysis guidelines for male youth athletes and similar to that suggested previously in the female literature [18, 24]. High-speed running, was defined as an effort > 4.58 $m.s^{-1}$, which represented the mean maximal aerobic speed (MAS) observed during piloting. The MAS was determined using the Maximal Aerobic Speed Test, with the final completed level achieved considered as the athletes MAS [131]. Sprinting (Sprint) was defined as an effort >5.55 $m.s^{-1}$, a threshold representing the MAS plus 30% of the aerobic speed reserve (e.g. maximal sprinting speed minus MAS). This latter method has been used in previous literature to individualize maximal velocity bands [24]. Maximal accelerations were defined as an effort > 2.26 $m.s^{-2}$, which represented 80% of players acceleration over 10 m and was established during piloting. As a player may continue to accelerate at a submaximal rate following a maximal acceleration, an acceleration effort was defined as beginning when the acceleration exceeded the threshold of 2.26 $m.s^{-2}$ and finishing when the acceleration dropped below 0 $m.s^{-2}$ [28]. Accelerations were calculated from speed data with a 0.3 s smoothing filter. Lastly, GPS was coupled with a 100 Hz accelerometer and was used to estimate PlayerLoad™, the instantaneous rate of change of acceleration, which is summed through all planes of movement to provide an arbitrary value or load [116]. Distance and high-speed running thresholds were presented relative to total match time (/min). Accelerations were presented as a count per minute of match-play. A minimum effort duration of 0.3 s was applied to all speed data.

Table 14: Mean ± SD of all key metrics in the $Peak_5$ of match-running during the first and second half of matches compared to each match factor of interest.

	Altitude		Temperature		Match outcome			Opposition ranking		Overall
	High (n = 455)	Low (n = 58)	High (n = 152)	Low (n = 361)	Win (n = 203)	Draw (n = 178)	Loss (n = 132)	Higher (n = 189)	Lower (n = 324)	All (n = 513)
Distance										
First half										
Absolute (m)	676 ± 48	701 ± 68	685 ± 80	702 ± 61	698 ± 64	677 ± 72	706 ± 69	698 ± 67	698 ± 67	698 ± 67**,[2]
$m \cdot min^{-1}$	135 ± 10	140 ± 13	137 ± 16	140 ± 12	140 ± 13	135 ± 14	141 ± 14	140 ± 13	140 ± 13	140 ± 13**, [2]
Second half										
Absolute (m)	653 ± 49	664 ± 64	643 ± 62	670 ± 62	667 ± 63	663 ± 57	655 ± 63	664 ± 61	663 ± 63	663 ± 63
$m \cdot min^{-1}$	131 ± 10	133 ± 13	129 ± 12	134 ± 12	133 ± 12	133 ± 11	131 ± 13	133 ± 13	133 ± 12	133 ± 13
High-speed running										
First half										
Absolute (m)	111 ± 37	115 ± 41	104 ± 44	118 ± 39	115 ± 8.3	102 ± 36	118 ± 37	112 ± 35	116 ± 43	115 ± 40*, [1]
$m \cdot min^{-1}$	22 ± 7.5	23 ± 8.1	21 ± 8.7	24 ± 7.7	23 ± 8.3	20 ± 8.1	24 ± 7.5	22 ± 7.0	23 ± 8.6	23 ± 8.0*, [1]
Second half										
Absolute (m)	95 ± 33	105 ± 37	94 ± 35	107 ± 37	106 ± 36	100 ± 41	102 ± 38	101 ± 38	106 ± 37	104 ± 37
$m \cdot min^{-1}$	19 ± 6.7	21 ± 7.5	19 ± 6.9	21 ± 7.5	21 ± 7.2	20 ± 8.1	20 ± 7.7	20 ± 7.6	21 ± 7.4	21 ± 7.4
Accelerations										
First half										
Absolute (Count)	15 ± 3.8	15 ± 3.1	14 ± 3.2	16 ± 3.1	16 ± 3.3	15 ± 3.4	15 ± 3.0	15 ± 3.1	15 ± 3.2	15 ± 3.2*, [1]
$Count \cdot min^{-1}$	3.00 ± 0.75	3.09 ± 0.62	2.87 ± 0.65	3.14 ± 0.62	3.12 ± 0.64	3.08 ± 0.68	2.99 ± 0.59	3.07 ± 0.62	3.08 ± 0.65	3.08 ± 0.64*, [1]
Second half										
Absolute (Count)	15 ± 4.1	14 ± 3.4	14 ± 3.7	15 ± 3.4	14 ± 3.4	15 ± 4.4	15 ± 3.5	15 ± 3.6	14 ± 3.4	14 ± 3.5
$Count \cdot min^{-1}$	2.97 ± 0.82	2.88 ± 0.68	2.81 ± 0.74	2.92 ± 0.69	2.88 ± 0.67	2.91 ± 0.87	2.91 ± 0.69	2.93 ± 0.73	2.87 ± 0.68	2.89 ± 0.70
PlayerLoad										
First half										
Absolute (AU)	72 ± 14	76 ± 14	74 ± 13	76 ± 14	75 ± 14	74 ± 10	76 ± 14	74 ± 13	68 ± 12	75 ± 14**,[2]
$AU \cdot min^{-1}$	14 ± 2.8	15 ± 2.8	15 ± 2.6	15 ± 2.8	15 ± 2.8	15 ± 2.0	15 ± 2.9	15 ± 2.6	14 ± 2.3	15 ± 2.8**,[2]
Second half										
Absolute (AU)	67 ± 12	70 ± 13	67 ± 11	71 ± 14	71 ± 14	68 ± 9.2	69 ± 13	76 ± 14	71 ± 14	70 ± 13
$AU \cdot min^{-1}$	13 ± 2.5	14 ± 2.7	14 ± 2.2	14 ± 2.8	14 ± 2.8	14 ± 1.8	14 ± 2.6	15 ± 2.9	14 ± 2.8	14 ± 2.7

Key: * = Small difference to second half; ** = Moderate difference to second half; [1] = Likely difference to second half; [2] = Very-likely difference to second half.

Statistical analysis

A paired sample t-test was used to identify GPS variables with peak values that were significantly different between halves (first vs. second), while a linear mixed model with the interaction of environmental, opponent ranks and half outcome between halves were used as fixed effects. A random effect for athletes and matches was employed to characterize the relationship between peak rolling averages of GPS variables and the mentioned interaction variables. The relationship between GPS variables and the match-factors of interest were determined using multiple regression models.

Chances of a greater or smaller substantial true difference were expressed quantitatively and calculated using a custom-made Excel spreadsheet [132]. These chances were expressed qualitatively for clear outcomes as follows: >25-75%, possibly; >75-95%, likely; >95-99%, very likely; >99%, almost certainly. The magnitude of a given effect was determined from its observed standardized value, as the difference in means divided by the between-subject standard deviation. The magnitude was expressed qualitatively as follows: <0.20, Trivial; 0.20-0.59, Small; 0.60-1.19, Moderate; ≥1.20 Large [124].

Results

The $Peak_5$ match-running of elite female soccer players are presented in Table 14, with reference to first and second half performances. The $Peak_5$ performance was found to be greater for all metrics, not accounting for match-factors, during the first half compared to the second half. Accelerations (6.0%, CL; 4.1%, 7.8%) and high-speed running (9.2%, CL; 6.3%, 12%) were likely greater in the first half compared to the second half. Whilst, distance (5.0%, CL; 2.5%, 7.5%) and PlayerLoad (7.1%, CL; 3.6%, 11%) were very likely greater during the first half compared to the second half.

The standardized effect sizes can be observed in Figure 4 for all metrics and match-factors of interest. $Peak_5$ distance likely decreased by a small magnitude (-3.6%, CL; -5.7%, -1.4%) during the first half of games at high altitude compared to low altitude, whilst a likely small decrease in the first half (-2.3%; CL, -3.9%, -0.8%) and a very-likely small decrease during the second half (-4.7%; CL, -6.8%, -2.6%) was observed for high temperature compared to low temperature. A draw compared to a loss likely increased distance by a small magnitude in the first half (4.3%; CL, 1.5%, 7.1%). A similar effect was observed in a draw compared to a win, with a possibly small increase in distance during the first half (3.1%; CL, 0.7%, 5.5%). No further meaningful effects were identified.

Examination of high-speed running $Peak_5$ resulted in no meaningful change when playing at high altitude during the first half, whilst a possibly small decrease was observed during the second half (-9.7%; CL, -18%, -1.3%). High temperatures possibly decreased high-speed running during the first (-12%; CL, -17%, -5.7%) and very-likely decreased high-speed running during the second half (-13%; CL, -19%, -6.5%) by a small magnitude. A loss compared to a draw likely increased high-speed running during the first half by a small magnitude (16%; CL, 5.8%, 26%), with a possibly small decrease also observed during the first half of a win compared to a draw (13%; CL, 2.8%, 23%). No other meaningful effects were observed.

The $Peak_5$ PlayerLoad was possibly decreased by a small magnitude during the first half (-5.0%; CL, -9.2%, -0.8%) of a match at high altitude compared to low altitude, whilst a possibly small decrease was only observed during the second half of a match in high temperatures compared to low temperatures (-4.9%; CL, -8.2%, -1.6%). No meaningful changes in performance were observed for match outcome.

No meaningful changes in $Peak_5$ acceleration performances were observed at high altitude compared to low altitude. High temperatures, compared to low temperatures, almost certainly decreased first half accelerations by a small magnitude (-8.7%; CL, -12%, -5.3%). No meaningful changes were observed in terms of opposition rankings.

Discussion

The aim of the current study was to determine the effect of match-factors on the peak match-running of elite female soccer players using a rolling 5-mins analysis. The main findings of this study were: 1) high temperature reduced $Peak_5$ accelerations in the first half, in addition to $Peak_5$ high-speed running and $Peak_5$ distance during both halves and PlayerLoad in the second half; 2) altitude decreased $Peak_5$ distance with changes observed in both halves; 3) first half distance and high-speed running $Peak_5$ were greater in a loss compared to a draw.

To the author's knowledge, this is the first study to examine the effect of high temperatures on $Peak_5$ match-running in soccer, male or female. Findings indicate a small decrease in both $Peak_5$ distance and $Peak_5$ high-speed running distance, which is in line with full match analyses [13, 69]. Match-running in temperatures >21°C have resulted in

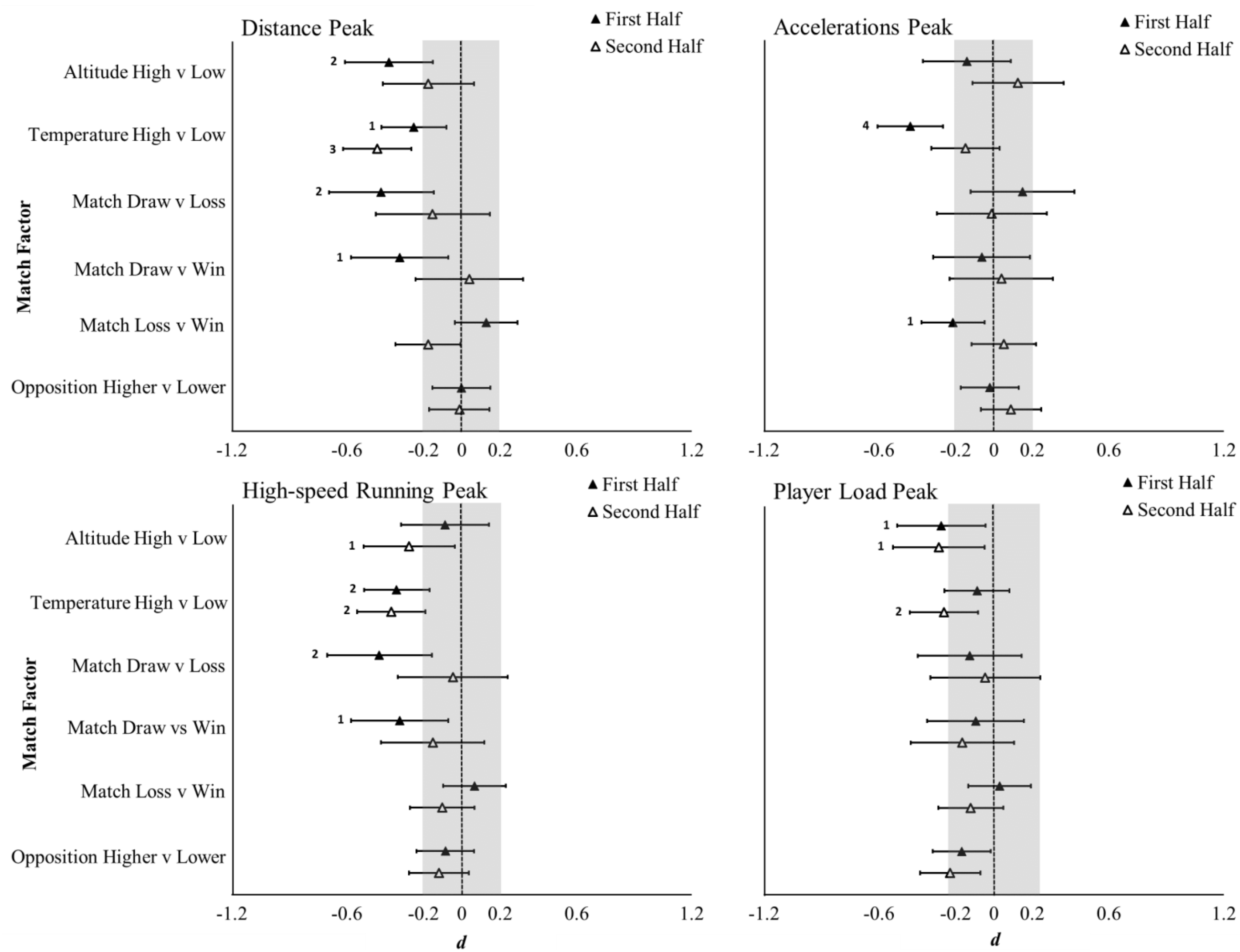

Figure 4: The effect of different match-factors on $Peak_5$ match-running of elite female soccer players presented as Cohen's D (90% Confidence Limits). 1 = Small possible change; 2 = Small likely change; 3 = Small very-likely change; 4 = Small almost certain change.

decreased high-speed running (-15%) and distance (-3.8%) [13]. Interestingly, no meaningful changes in high-speed running were observed in a full match analysis of the same dataset, suggesting that players may pace their movement differently across a match in high temperatures so as not to compromise high-speed actions when required, such as prior to goal scoring or crossing [36]. Alternatively, the perception of effort in the heat may compromise a players' ability to cover large high-speed distances during any given 5 min period [106]. However, heat-induced changes in match-running performance are not well understood physiologically. Controlled studies analysing simulated $Peak_5$ periods could be utilised to analyse the physiological effects, such as lactate accumulation or core temperature, of these periods of match-play. A better understanding of what limits player movement in a $Peak_5$ period and how this can be minimized to better optimize a player's physical performance.

Distance $Peak_5$ was lower during the first half of performances at altitude compared to sea-level, whilst high-speed running was lower during the second half. Playing at 1600-3600 m has shown to decrease $Peak_5$ distance (-5.7 to -23%) and high-speed running (-21 to -35%) in male youth soccer players [11, 38]. However, performances over two halves were not examined so it is uncertain whether these changes occurred predominantly in one-half over the other. Despite the facilitation of high-speed running experienced at altitude [108], a slowing in ATP re-synthesis following fatiguing exercise has been observed in hypoxic conditions [109]. This will be most evident during the most intense period of the match, where recovery periods are shortened. Changes in high-speed running and accelerations in the current study were only possibly different to that of sea-level performances, suggesting these factors may not be affected at altitude. Practitioners should be aware of the change in $Peak_5$ distance whilst playing at altitude >500m and how this could affect tactical game plans, such as how long a team can press or counter attack at high-speed.

Greater running distance in the first half was associated with a loss compared to a draw. High-speed running was, however, lower in the first half of matches that were lost compared to drawn, with no meaningful changes in the second half. In male soccer, greater high-speed running (11.3%) was observed in Spanish Premier League teams when losing compared to winning a match [42]. Whilst, male English Premier League attackers performed a greater percentage of high-speed running when winning a game compared to losing [15]. Tactical approaches may differ with the defensive organization in the women's game improving in recent years, resulting in more shorter passes in an attempt to penetrate the defence [137]. Additional information such as the half-time score line or state of the game, such as winning or losing, would possibly provide a better insight into how match-running may be related to outcome. The inclusion of technical and tactical data is suggested to confirm these findings, particularly in an attempt to characterize the differences in the male and female game on match-running in soccer.

The current study was limited in that performance was not examined by position. It is understood physical outputs can differ by position due to differences in match-running profiles, such as between a centre back and full back [16]. Due to the small sample size utilised this was not possible in the current study to obtain significant findings. This may explain the various unclear and small findings observed, with a larger sample required to strengthen the spread of the data. Finally, the method of collecting temperature may not provide a truly accurate representation of the temperature present within the stadium. As this study was retrospective in nature, it was not possible to collect temperature from inside the stadium of all games. Researchers should use an appropriate thermometer within the stadium, assessing temperature prior to kick-off.

This research provides an initial detailed overview of the effects of match-factors when utilizing a rolling 5-mins analysis in elite female soccer. Overall these various factors appear to have minimal effects on match-running. This may be due to the large CVs observed for $Peak_5$ values, particularly high-speed running, accelerations and PlayerLoad. This data can be utilised to identify the period of greatest running, or worst-case scenario, to help guide training protocols to prepare players appropriately.

Practical applications

The findings of this study indicate $Peak_5$ match-running may be influenced by match-factors. This data can be used to inform training protocols to prepare players for these running periods. The design of small-sided games to increase player work-rate to match these periods would be most appropriate, however, the inclusion of interval training protocols may be necessary. Further research is required to examine how to implement this information directly into training scenarios.

Technical coaches can use this information to help guide player selection based on performances in different scenarios. For example, the information could guide when to utilise players with different physiological profiles to best influence the game utilizing longitudinal trends in match performances. Whilst, this information also provides technical coaches with an understanding of what their players can physically handle when faced with these match-factors.

Section 3: In-depth examination of match-factors on player readiness and match-running performance

Chapter 6: Brief report: A comparison of match-running between full game, early and late substitutes in elite female soccer

Chapter 7: Is athlete readiness and match-running performance affected during a congested match schedule in elite female soccer?

Chapter 8: The reduction of match-running in elite female youth soccer players at 2250 m

Chapter 6: Brief report: A comparison of match-running between full game, early and late substitutes in elite female soccer

This chapter comprises of the following paper prepared for Journal of Strength and Conditioning Research.

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Author contribution:

Trewin J, 80%; Meylan C, 10%; Varley MC, 5%; Cronin J, 2.5%; Ling D, 2.5%.

Prelude

Most match-running analyses and the analyses to this point of the thesis has focused on the performance of 90 min players. However, the performance of substitutes has not been examined in a female population previously and should provide further insight into match-running of elite soccer players. It has been suggested that players pace themselves through a match, so they can maintain performance throughout. It is not well understood how substitutes pace themselves, or if they pace their movement at all. Late substitutes (<22.5 min of the second half) might exhibit an all-out pacing strategy, whilst early substitutes (>22.5 min of the second half) may pace themselves to maintain performance throughout the half. Research on this topic is limited, particularly in women's soccer. The purpose of this study therefore, is to examine the difference in match-running between full match, early substitutes and late substitutes.

Introduction

Soccer is a team sport where three substitutions are allowed, which may be used to stabilize the defence or provide an attacking stimulus during the second half of a match. It is believed that starting players may pace their movement profiles in an attempt to last the full match [82], whilst information relating to substitutes is limited [51, 138, 139]. Most substitutions tend to occur between 60 to 85-mins of the match, with the attacking intent of substitutes increasing the later they are introduced [139]. These players tend to cover greater high-speed running distances, although they may not utilise their full physical potential [138, 139]. It is important to note that replaced forwards and midfielders have been shown to maintain work-rates between the first and second halves, indicating substitutions are not necessarily fatigue related [138].

Studies often limit the inclusion of players to those that play a full game to limit variation player performances. Whilst a substitute may utilise an all-out strategy when entering the match late, such as the last 20 mins [51]. However, this term does not take into account the tactical role of the substitute player who may be utilised to strengthen the team's defensive qualities. Further, it is not well understood what strategies substitutes utilise when entering the match early in the second half [82]. Therefore, the purpose of the current study is to examine the performance of elite female soccer players who play a full match or enter the match as an early or late substitute.

Methods

Player movement of elite female soccer players (n = 45) from the same senior national team, ranked in the top 10 in the world, was recorded and tracked across four years (2012-2015) and 42 international fixtures (Files = 462). All players provided informed consent to participate in longitudinal tracking and data analysis, which was approved by the University of Victoria Human Research Ethics Board. Raw velocity data was collected via global positioning system (GPS) technology sampling at 10-Hz (Minimax S4, Catapult Innovations, Australia) and analysed using a custom spreadsheet. Player movement categories were defined as per Table 15 and the average number of satellites and horizontal dilution of precision for games was 11.9 ± 0.4 and 0.96 ± 0.05 respectively. Players were characterized as full-match, early (>22.5 mins played) or late (<22.5 mins played) second half substitutes, with mean minutes played and minutes range observed in Table 16.

Due to the clustering nature, data were examined using a negative binomial mixed model using STATA (v13, StataCorp, College Station, TX). An inference about the true value of a given effect, was based on its uncertainty in relation to the important difference, assumed to be 0.20 of the standard deviation between players in an average match. This was derived from the mixed model by adding the variance for the true differences between players with the match-to-match variance within players, before taking the square root. Inferences were non-clinical, with an effect deemed unclear if the 90% confidence interval included the smallest important positive and negative differences; otherwise, the effect was deemed clear. Chances of a greater or smaller substantial true difference were expressed quantitatively and calculated using a custom-made Excel spreadsheet [132]. These chances were expressed qualitatively for clear outcomes as follows: >25-75%, possibly; >75-95%, likely; >95-99%, very likely; >99%, almost certainly. The magnitude of a given effect was determined from its observed standardized value (the difference in means divided by the between-subject standard deviation. The magnitude was expressed qualitatively as follows: <0.20, Trivial; 0.20-0.59, Small; 0.60-1.19, Moderate; ≥1.20 Large [124].

Table 15: Locomotor guidelines used to set gender specific speed thresholds.

Metric	Speed threshold	Locomotor guidelines or physiological markers
Total distance ($m.min^{-1}$)	All movement	
High-speed Running ($m.min^{-1}$)	>4.58 $m.s^{-1}$	Mean maximal aerobic speed assessed using the maximal aerobic speed field test.[4]
Low-speed running ($m.min^{-1}$)	<4.58 $m.s^{-1}$	All movement below the high-speed running threshold.
Maximal accelerations ($Count.min^{-1}$)	>2.26 $m.s^{-2}$	80% of Mean 10 m acceleration during piloting.
PlayerLoad ($AU.min^{-1}$)	All movement	Sum of accelerations through each movement plane.
Minimum effort duration	0.3s	Minimum time spent above the threshold to count as an effort within HSR/min, Sprint/min, and Accel/min.

Results

Mean and SD of all data are presented in Table 16, with the standardized change presented in Figure 5. Late substitutes performed the greatest Total distance compared to both full-match (6.5%; CL 3.4%, 9.5%) and early substitutes (6.5%; CL, 3.4%, 9.6%). There was no meaningful difference between the total distance/min of full-match and early substitutes (0.0%; CL, -1.7%, 1.6%). The total low-speed running was moderately greater between early substitutes and late substitutes (4.0%; CL, 2.1%, 5.9%), whilst only a small difference was present between full-match and late substitutes (3.3%; CL, 1.4%, 5.2%). The largest differences were observed in high-speed running with late substitutes performing the greatest amount compared to ESUB (26%; CL, 14%, 39%) and full-match players (34%; CL, 18%, 50%). A small difference in high-speed running was also observed between full-match and early substitutes (7.3%; CL, 0.6%, 14%). Only small possibly increases in accelerations were observed between late substitutes and both early substitutes (4.6%; CL, -1.7%, 11%) and full-match players (5.3%; CL, -1.0%, 12%).

Discussion

The aim of the current study was to examine the differences between full-match, early substitutes and late substitutes match-running performances to ascertain the possible pacing strategies utilised. The major findings were: 1) the match-running performance of late substitute players exhibited a greater relative match-running, with moderate to large difference reported for total distance, low-speed running and high-speed running; and, 2) there were no meaningful differences between the performances of full-match and early substitute players, except for greater high-speed running performed by early substitutes.

Table 16: A comparison of full match and early or late substitutes minutes played and match-running profiles (mean ± SD).

	Full match (n = 30, files = 277)	Early substitute (n = 38, files = 126)	Late substitute (n = 33, files = 59)
Minutes played (mins)	92.5 ± 6.0	34.9 ± 9.4	16.1 ± 4.3
Minute range (mins)	75.6-104.4	22.6-50.7	5.7-22.3
Total distance ($m \cdot min^{-1}$)	108 ± 9.7	110 ± 13	119 ± 12
Low-speed running ($m \cdot min^{-1}$)	97.8 ± 8.1	98.7 ± 9.6	104 ± 8.7
High-speed running ($m \cdot min^{-1}$)	9.7 ± 3.3	10.9 ± 4.8	14.7 ± 5.8
Accelerations ($accel \cdot min^{-1}$)	1.81 ± 0.38	1.82 ± 0.41	1.92 ± 0.55
PlayerLoad ($PLoad \cdot min^{-1}$)	11.3 ± 2.3	12.0 ± 2.1	12.8 ± 1.7

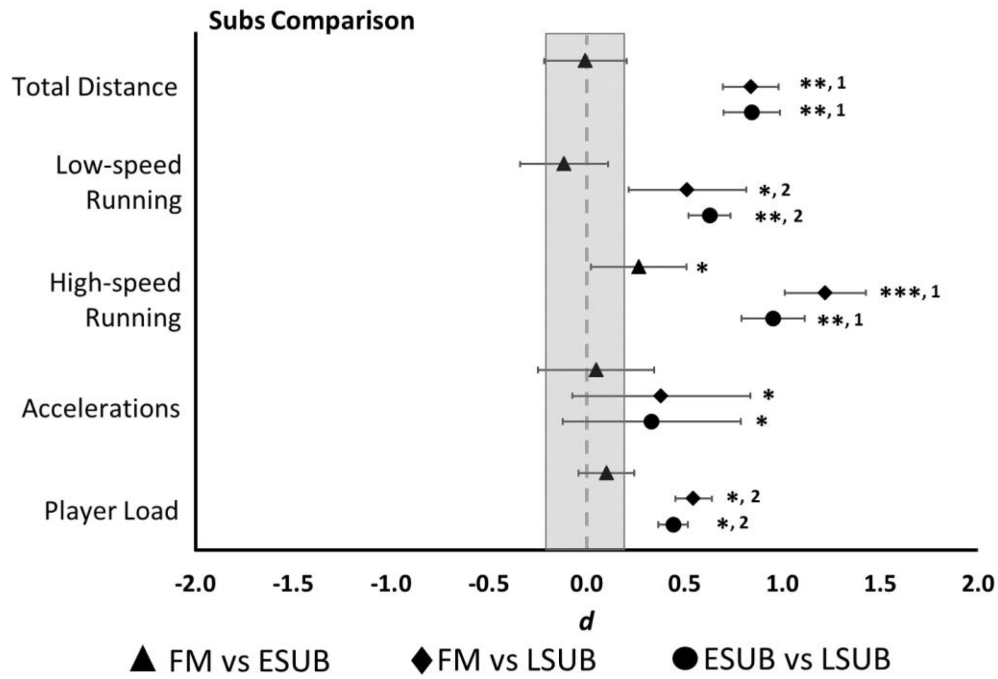

Figure 5: Standardised change in the means of Full-Match and players considered Early Substitutes (>22.5mins played) or Late Substitutes (<22.5mins played) in the second half of elite female soccer matches. Key: * = small; ** = Moderate; *** = Large, [1] = Very likely; [2] = Almost Certainly.

With a short time to influence match outcome, it has been suggested that substitutes may employ an all-out type of pacing strategy, which is dependent on match situation and coach instructions [82]. It could be considered that late substitutes are often utilised to stimulate a team to maintain or push for a win or draw through an increased work-rate [138]. Further, key match moments (such as shots and crosses) have been suggested to occur following a period of high-speed running [36], with LSUB reporting moderate to large differences observed for high-speed running (ES = 0.95-1.22) compared to full-match and early substitutes. This may strengthen the notion of substitutes looking to influence match outcome, however, further research is required to ascertain what magnitude of high-speed running occurred prior to key match moments or was the result of defensive transition. This may be aided by the inclusion of coach instruction as to whether the substitute is used defensively or to stimulate an attack. Further, the training stimulus for these players should be considered based on if they are required to start a match, they may not be able to sustain their physical work-rate due to an inefficient pacing strategy. Whilst within match, players should perform a high-intensity warm-up prior to substitution to possibly aid in the performance of high-speed running they are likely to experience [140].

The findings of the current study suggest the match-running of early substitutes players was not meaningfully different to that of full-match. To the author's knowledge, this is the first-time early substitutes have been compared to full-match players. Previous research has observed early substitutes cover greater total distance (6.9%) and high-speed running (14%) when examining the equivalent time period in a full match performance [51]. However, this finding may be biased by the time period examined for the early substitutes, with the most intense period reported to be within 10 mins of either substitution or the beginning of the match for full-match [138].

Substitutes appear to differ in movement, with late substitutes meaningfully different to both early substitutes and full-match players. However, this study is limited in that it did not examine the last 22.5mins of the match in both full-match and early substitutes players. Further, positional differences may also be important whilst the inclusion of coach instructions to substitutes may aid interpretation of differences observed. These findings may be utilised to inform training protocols to provide the appropriate stimulus for players often used as substitutes to prepare them for full match performances if required.

Practical applications

The present findings are an initial investigation into the work-rates of early and late substitutes in elite female soccer. Findings reveal a large difference in player movement compared to early substitutes and full-match players for late substitutes. This is particularly important for the type of training stimulus these players receive so that they can sustain a 90min work rate if required. Current practice may lean toward a shorter session to enhance the anaerobic system, whilst it may be more relevant to expose these players to a higher volume stimulus.

Meanwhile, the greater relative match-running performed by the late substitutes in the current study may not be applicable to all players considered late substitutes. The instruction of the coach and the type of tactics employed may play a significant role in match-running completed. A player used to stabilize a team will provide a different work-rate to one introduced to enhance attacking potential or provide defensive aggression. Further research is required to fully examine the contribution of substitutes in elite soccer, with the possible inclusion of coach-to-player instruction to assist definition of a pacing strategy.

Chapter 7: Is athlete readiness and match-running performance affected during a congested match schedule in elite female soccer?

This chapter comprises the following paper prepared for the Journal of Sports Sciences.

Reference: Trewin J, Meylan C, Chang-Tsai M, Varley MC, Cronin J. Is athlete readiness and match-running performance affected during a congested match schedule in elite female soccer? *J Sport Sci.* 2017.

Author contributions:

Trewin J, 80%; Meylan C, 7.5%; Chang-Tsai M, 7.5%; Varley MC, 2.5%; Cronin J, 2.5%.

Prelude

Previously in Chapter 4, it was established that the time between two successive matches had no effect on the match-running of elite soccer players. A tournament setting, where four games are played within 8-days, may provide a better scenario for examining the effects of a congested schedule on match-running, particularly if players started and completed the majority of all four matches. Furthermore, a recent review of congested schedule research has highlighted the need for a more holistic approach. One method might be examining subjective ratings of readiness throughout a period of successive matches, an approach that often has not been taken into account. Furthermore, the examination of neural fatigue as measured via vertical jump testing may provide an objective overview of player fatigue. Taking such a holistic approach, whilst also having athletes who start every game may provide a better insight as to whether congested schedules impact performance or readiness to play. The purpose of this study therefore, was to examine the readiness and match-running of elite female soccer players during a period of successive matches.

Introduction

The distribution of matches in male soccer can often result in congested fixture periods, with multiple games within 3-4 days of each other [141]. This scenario is intensified in female international soccer, where tournaments can include four games within an eight-day period, with a maximum of 48 hours' recovery (e.g. Cyprus Cup and The Algarve Cup). Research has consistently shown recovery can take up to 72 hours to achieve pre-match levels, particularly in jump or sprint tests [30, 142]. Therefore, match-running performance could be expected to decline during congested fixture periods, due to the recovery of central and peripheral fatigue following a match [143], which may primarily be a result of repeated eccentric actions experienced during acceleration and deceleration [144]. However, recent investigations do not appear to examine the within player response to fixture congestion, accounting for the individual variation from match-to-match [45, 83]. The extent to which players are exposed to congested schedules has been questioned in elite male soccer [145], however, the completion of successive matches may occur more frequently in international tournaments where the best players are required in every match.

In an effort to improve congested fixture research, a recent review has suggested the use of a more holistic approach [84]. Research has focused on the match-running changes throughout a congested period, whilst often disregarding perceptual ratings, such as perceived exertion (RPE), fatigue or soreness [84]. Research has shown changes in sleep quality and quantity during periods of increased training load [65, 146], which may be present during fixture congestion. Whilst subjective, RPE has been successfully used in research to quantify internal load [56]. Utilizing such a method to quantify accumulated load may give a further insight into match-to-match changes observed in match-running metrics, whilst also accounting for a perceptual internal load which may not vary as much as a between player external load. Alternatively, the use of a performance test to quantify associated neuromuscular fatigue (NMF) may be of importance. Male soccer is characterized by as much as 1800 explosive accelerations and decelerations during a single match, of varying magnitude [119]. Therefore, these actions may induce NMF, which may accumulate throughout a congested period, due to the heavy eccentric loading during these actions. Research has identified a countermovement jump analysis using force platforms as a reliable test, whilst also providing a suitable method to monitor athlete NMF [98, 147]. The use of these variables provides a more holistic approach, compared to match-running alone, that may help identify alternative changes occurring during successive matches. Therefore, the aim of the current study was to examine the changes in match performance, readiness, and NMF during a period of fixture congestion in elite female soccer players.

Methods

Participants

Members of the Women's Canadian National team (n = 18, age = 25.2 ± 4.9, height = 168.5 ± 6.4 and weight = 65.3 ± 6.4) were monitored during a eight-day international tournament consisting of four games (Figure 6). All athletes signed an informed consent form, agreeing to the aims of the study, with ethics granted by Victoria University Human Research Ethics Board. The tournament comprised of three group stage matches and a final, with a day rest between match 1-2 and 3-4, with two days' rest between match 2-3, with all matches played at least 90 minutes in duration. The opposition was European or Asian based teams offering vastly different tactical approaches. All athletes were monitored using GPS (Minimax S4, Catapult Innovations, Australia), daily wellness measures and NMF jump assessments. To isolate the effect of successive matches, only players who played in all four games were analysed (n = 8, age = 27.6 ± 4.5, height = 167.1 ± 7.8, and weight = 67.0 ± 6.2), with a timeline of all measurement points presented in Figure 6. Players played in the following positions; FWD (n = 3), MF (n = 2), FB (n = 2) and CB (n = 1); with average match playing time of 87.6 ± 12 min.

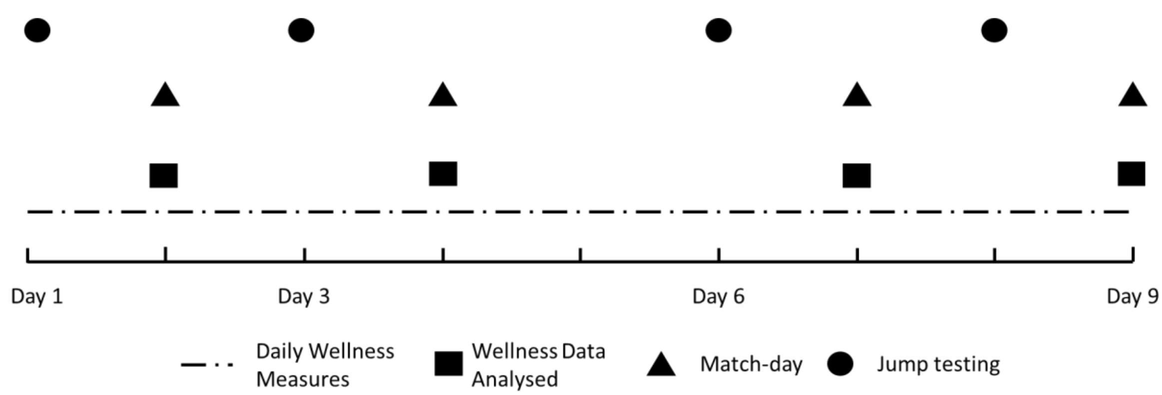

Figure 6**:** Timeline of matches, wellness and jump analysis data collection points throughout the congested period.

Wellness and jump analysis

Player wellness was collected using subjective ratings on a 10-point scale (e.g. 1-bad to 10-good) using a custom questionnaire (Table 17). Players were familiarised to the wellness scales during a during a three-week collection period prior to the start of the tournament. Data from match-days was used for statistical analysis purposes. A portable force platform sampling at 200-Hz (PS-2142, Pasco Scientific, USA) was used to examine NMF via jump analysis. With hands on their hips, players performed three maximal countermovement jumps to a self-selected depth, with 30s rest between jumps [148]. Raw data were exported from manufacturer software (Capstone 1.3, Pasco Scientific, USA) and analysed using custom-built software. The NMF variables of interest, and coefficient of variation (CV) and 90% confidence limits (CL), were; force at zero velocity (CV = 9.1%, CL, 7.2%, 14%), take-off velocity (CV = 3.9%, CL, 3.2%, 5.8%), relative mean concentric power (CV = 7.5%, CL, 6.0%, 11%), relative mean eccentric power (CV = 24%, CL, 19%, 37%) and the eccentric-concentric power ratio (CV = 17%, CL, 13%, 26%). A post-match coach rating (1-5) and RPE (1-10) were collected on/from all players. The RPE score was multiplied by playing time (session RPE, sRPE) and used to examine the effect of accumulated loading on match-running performance [56]. There was one training session during the competition period with a mean total distance of 3604 m ± 615 m and sRPE of 248 ± 85 units.

Table 17: Wellness variables and scales utilised with quantitative terms presented.

Variable	1.	10.
Fatigue	Not fatigued	Very very fatigued
Motivation	Unmotivated	Very very motivated
Stress	Not stressed	Very stressed
Mood	Very very sad	Very very happy
Sleep quality	Very very poor	Very very good
Sleep Hours (hours)	Time input	

Match analysis

Player movement was recorded using GPS sampling at 10-Hz positioned between the shoulder blades of each player in a custom-made vest. Raw files were exported from manufacturer software (Sprint 5.1, Catapult Innovations, Australia) and analysed using a custom-built MS Excel spreadsheet (2013, Microsoft, United States of America). Speed was calculated using the Doppler shift method, as opposed to differentiation of positional data [28]. This method is associated with a higher level of precision [114]. The average number of satellites and horizontal dilution of precision for games were 10.6 ± 0.5 and 0.97 ± 0.05 respectively. Match outcome and opposition rankings are presented in Table 18.

Thresholds were set using previously described locomotor guidelines for male youth and similar to that suggested in previous female literature [18, 24]. Total distance encompassed movement at each threshold. High-speed running (≥4.58 $m.s^{-1}$) represents the mean aerobic speed observed during piloting, determined using the Maximal Aerobic Speed Test [131]. Sprinting represents the mean aerobic speed plus 30% of the aerobic speed reserve (calculated as maximal sprinting speed minus mean aerobic speed). This latter method has been used in previous literature to individualize maximal velocity bands [24]. Low-speed running was defined as any distance covered at <4.58 $m.s^{-1}$. Maximal accelerations (>2.26 $m.s^{-2}$) represents 80% of player accelerations over 10 m established during piloting. As a player may continue to accelerate at a submaximal rate following an acceleration, an acceleration effort was defined as beginning when acceleration exceeded the threshold and finishing when the acceleration dropped below 0 $m.s^{-2}$ [28].

Statistical analysis

Raw data were presented as mean and standard deviations, with co-efficient of variations (CV) calculated using log transformed data, to remove the chance of bias from non-uniform data. Normative CV were presented from a recent study using the same cohort of players [128]. Match-running data was presented as a percentage change, from match 1, plus standard deviation. Smallest and moderate worthwhile changes were calculated as 0.2 and 0.6 of the standard deviation of match-running data from match 1. Wellness data was presented as the mean ± standard deviation throughout the entire collection period. All wellness and jump data were standardized to a three-month pre-tournament collection period. A one-way repeated measures ANCOVA mixed model was performed on wellness, NMF, and GPS data to identify the difference between each individual match and to control for accumulated loading. Accumulated loading was calculated as the sum of the previous games' load, defined as sRPE. A Tukey post-hoc procedure to control for type I error in making multiple comparisons was also applied. Chances of a greater or smaller substantial true difference

Table 18: Mean ± SD for all match-running metrics by game presented relative to minutes played.

	Match 1	Match 2	Match 3	Match 4	Co-efficient of Variation (%, 90% Confidence Intervals)	Co-efficient of Variation Norm (%, 90% Confidence Intervals)
Opposition Ranking	21	17	14	6		
Match outcome	2-0	1-0	1-0	0-1		
Minutes played	84.5 ± 9.2	90.7 ± 8.6	81.6 ± 16.7	94.7 ± 7.8		
Total distance						
Absolute (m)	9425 ± 1071	8574 ± 782	8205 ± 1598	10023 ± 794	12 (12, 13)	6.4 (5.8, 7.1)
$m \cdot min^{-1}$	112 ± 6.0	94.8 ± 6.3	101 ± 8.0	106 ± 8.1	7.8 (7.6, 8.3)	6.8 (6.2, 7.6)
Low-speed running distance						
Absolute (m)	8500 ± 1120	7786 ± 787	7976 ± 1518	9010 ± 813	12 (12, 13)	6.1 (5.6, 6.8)
$m \cdot min^{-1}$	101 ± 5.5	86.0 ± 4.9	90.6 ± 5.3	95.4 ± 6.8	7.5 (7.3, 7.9)	6.5 (5.9, 7.2)
High-speed running distance						
Absolute (m)	926 ± 237	789 ± 168	830 ± 232	1013 ± 167	19 (18, 20)	32 (30, 36)
$m \cdot min^{-1}$	11.2 ± 3.3	8.9 ± 2.4	10.6 ± 3.5	10.8 ± 2.5	17 (17, 18)	33 (30, 37)
Accelerations						
Absolute (Count)	160 ± 20	182 ± 27	160 ± 41	174 ± 32	12 (12, 13)	16 (15, 18)
$count \cdot min^{-1}$	1.91 ± 0.27	2.02 ± 0.32	1.98 ± 0.36	1.85 ± 0.36	8.1 (7.9, 8.6)	17 (15, 19)

were expressed qualitatively using a custom-made Excel spreadsheet [132]. These chances were expressed qualitatively for clear outcomes as follows: >25-75%, possibly; >75-95%, likely; >95-99%, very likely; >99%, almost certainly. Findings were assessed using the standardized change in the mean using Cohen's D with 90% confidence intervals. The magnitude was expressed qualitatively as follows: <0.20, Trivial; 0.20-0.59, Small; 0.60-1.19, Moderate; ≥1.20 Large [118].

Results

Match-running

The mean ± SD match-running of the four games is presented in Table 18. Changes in match-running from match-to-match are shown in Figure 7. An almost certain moderate decline in total distance was observed between match 1-4 (ES = -0.69, P = 0.001). This coincided with an almost certain moderate decline in low-speed running (ES = -0.76, P < 0.001) between match 1-4, whilst almost certain large changes were observed between match 1 and both match 2 (ES = -2.19, P < 0.001) and 3 (ES = -1.45, P < 0.001). Changes in high-speed running were trivial between match 1-4, whilst a very-likely moderate decline was observed between match 1 and 2 (ES = -0.61, P = 0.006). Accelerations differences were almost certainly trivial from game one to two (ES = 0.38 P > 0.05) and game one to three (ES = 0.22, P > 0.05). When accumulated loading was considered, very likely and almost certain meaningful changes remained present for low-speed running between matches 1-2 (ES = -2.97, P < 0.001) and 1-3 (ES = -2.08, P = 0.050).

NMF jump analysis

No meaningful changes in the variables of interest were observed during successive matches.

Wellness, coach rating, and sRPE

Descriptive data (mean ± SD) of all wellness data is observed in Figure 8 from day-to-day over the collection period. Match-day data showed no meaningful changes in all variables except sleep hours, for which a moderate decline was observed from match 1-4 (ES = -0.94, P < 0.001). There were no meaningful changes from match-to-match for coach ratings or sRPE.

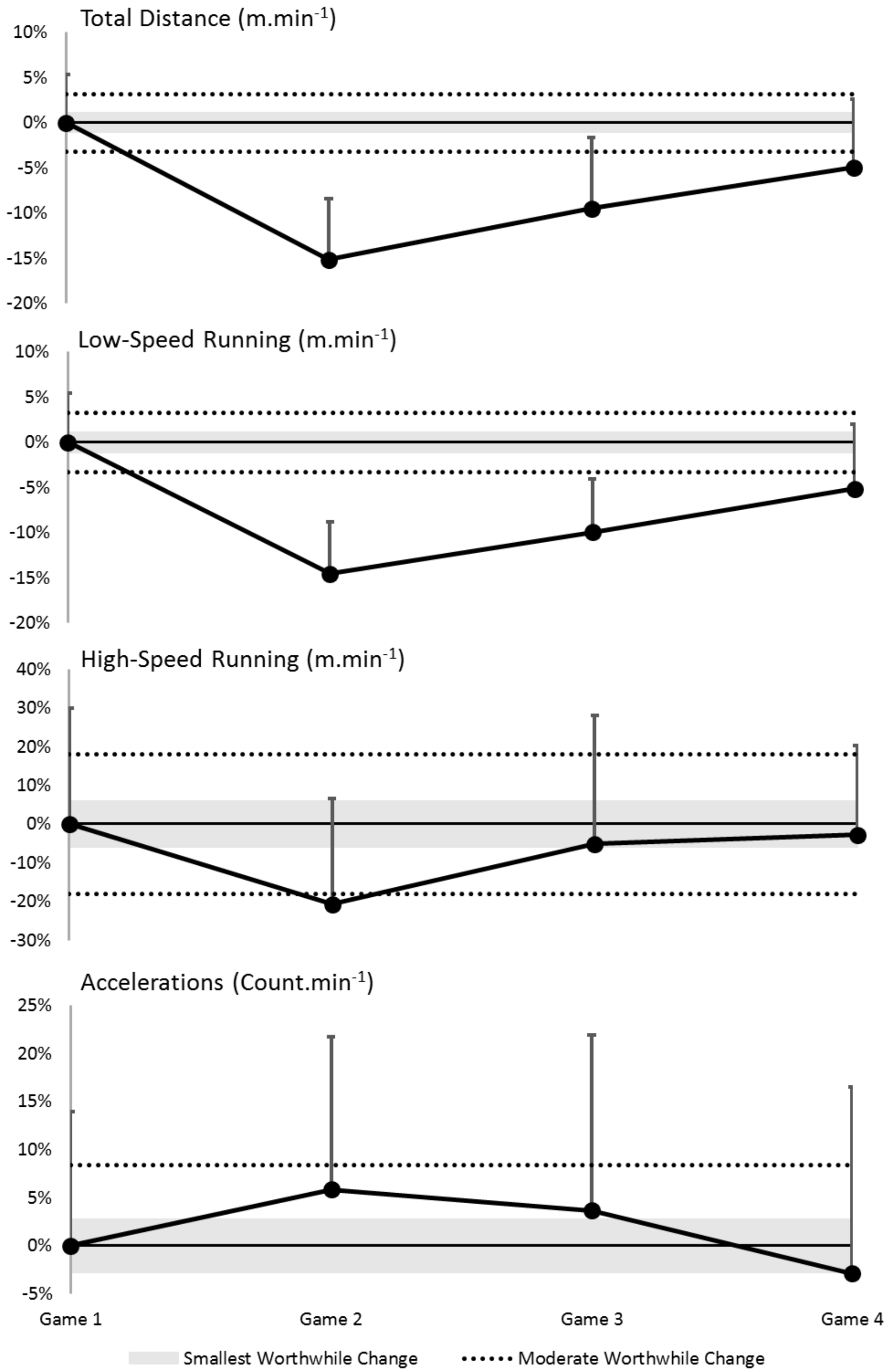

Figure 7: Change in match-running performance from game to game in reference to game 1. The shaded area represents trivial changes and the dash line represents the lower limit for moderate changes (<0.20 and >0.60 of between subject variation of Game 1, SD). Bars are the SDs for each game observed.

Discussion

This study examined a period of fixture congestion in elite female soccer, where players were exposed to four matches in eight days. This was also the first study to utilise a holistic method by examining NMF and daily wellness variables, in addition to measures of match-running performance. The major findings of the current study were: 1) the use of simple reliable metrics such as total distance and low-speed running may be the most sensitive to repeated matches; 2) inclusion of accumulated loading may account for changes in match-running performance between the first and last matches; 3) despite <72 hours of recovery, both NMF, and acceleration ability observed no meaningful changes from the first to the last matches; and, 4) fixture congestion may affect the number of hours' players sleep per night, which is an important consideration for player recovery.

The major findings of the current study were that total distance and low-speed running were 5% lower in match four compared to match one. Analysis of all other outcome measures were found to have no meaningful differences. The largest decline was observed between match one and two, with total distance and low-speed running 15% lower. With total distance and low-speed running in subsequent matches remaining decreased, possibly suggesting an element of fatigue or an altered pacing strategy. Players may limit low-speed running to maintain high-speed and explosive actions for important match situations, such as crosses and counter-attacks, similar to findings observed at high temperatures [107]. From these findings, it would seem that simple and reliable measures of performance may be the most sensitive to periods of fixture congestion. A similarly large finding was observed in youth soccer, albeit in five 50-60 minute matches over three days, with total distance decreasing by a large magnitude (ES = -1.16) between match one and five [71]. Whereas other congested fixture literature has observed no significant changes in match-running measures [35, 45, 46, 72, 83, 141]. These studies, however, appear to assess changes using an overall team mean, which may not be appropriate to account for differences in player fitness levels or recovery kinetics, whilst also not accounting for changes in team personnel [149]. The current study assessed within player changes whilst only using players who played in every match. Researchers should utilise this method, whilst practitioners should be aware of the subsequent effects the initial match of successive matches may have on match-running in the following matches.

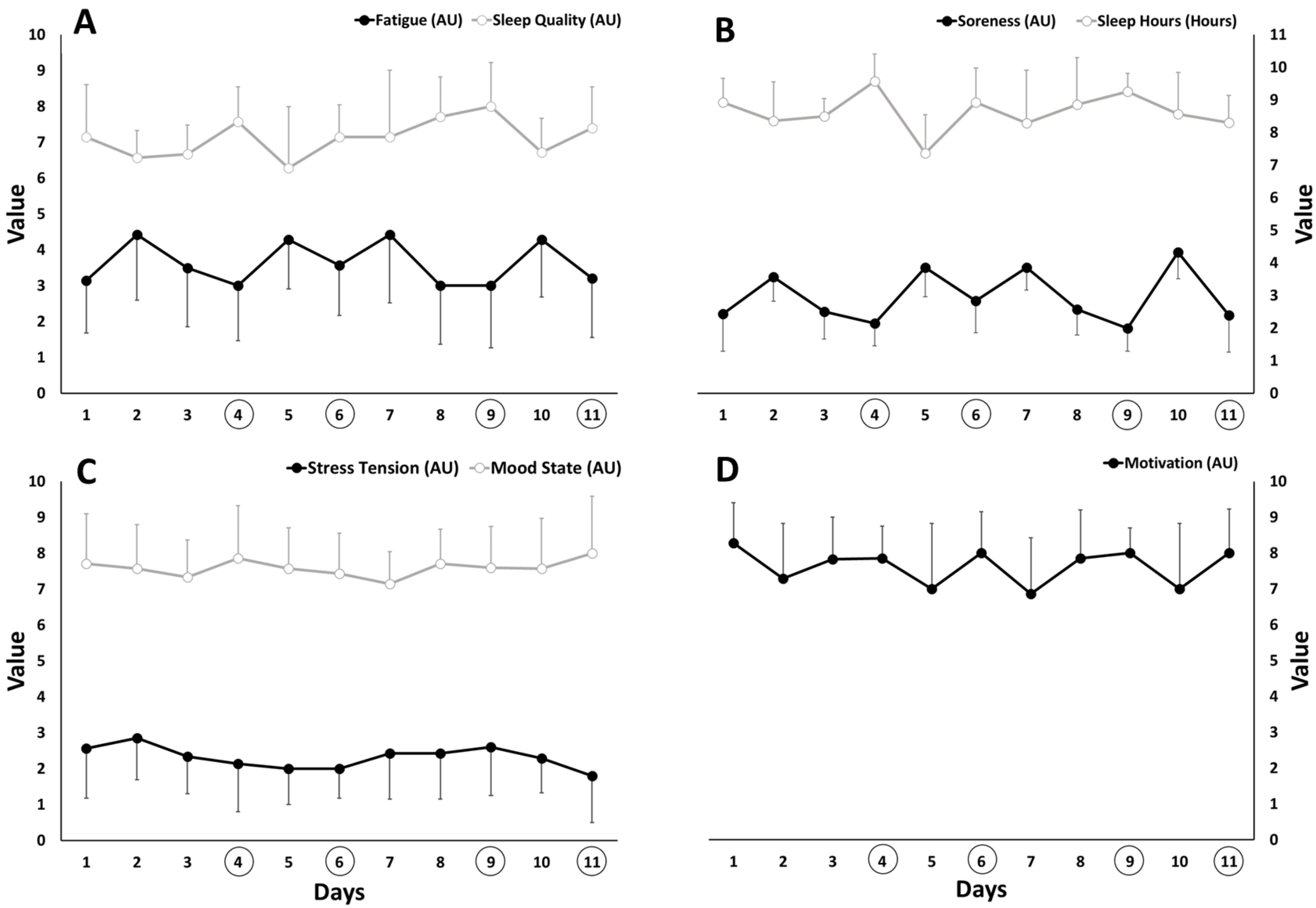

Figure 8: Daily wellness data collected throughout the congested fixture period presented as mean ± SD. Changes are presented for: fatigue and sleep quality (panel A); soreness and sleep hours (panel B); stress tension and mood state (panel C); and motivation (panel D). Circled days indicate when a match occurred throughout the examined period.

A novel finding of the current study was that changes in match-running were accounted for by accumulated loading. Through the examination of sRPE of preceding matches, the changes in total distance and low-speed running were no longer considered meaningful. These findings suggest that the changes in total distance and low-speed running were related to the accumulated load the players were exposed to, rather than a biological variation of match-running performance. No research to date has examined this aspect on physical match-running performance in team sports. It is understood that following a match glycogen re-synthesis may take 48 hours or greater to reach pre-match levels [150, 151]. Glycogen is predominantly utilised for high-speed actions, with depletion of glycogen stores resulting in declined high-speed running distance towards the end of a match [67]. Depleted glycogen levels could be a possible cause for the decline in high-speed running performance from match one to two. With increased recovery from match two to three allowing for greater glycogen re-synthesis and increased high-speed running distance. During periods of high fixture congestion where players are likely to play multiple matches back to back nutritional strategies should focus on increased carbohydrate intake to increase glycogen levels pre- and post-match.

The examination of NMF via jump analysis revealed no meaningful changes. This coincided with no meaningful negative changes in acceleration performance within a match. Acceleration is regarded as the most energetically demanding actions present in soccer [26, 30]. Further, acceleration and deceleration actions have been reported as large contributors to muscle damage determined by creatine kinase concentrations 24 hours post an Australian Rules football match [29]. One study examined the influence of soccer player actions on recovery kinetics, finding countermovement jump performance to be significantly decreased up to 72 hours' post-match (ES = 1.13), with a large relationship (r = -0.55) observed with hard changes of direction [30]. Jump height was not examined in the current study as it was determined via indirect mathematical assumption, which has shown no change in jump height in previous longitudinal analyses [148]. However, increased training load in female rugby has shown to decrease force produced at zero velocity [148]. No change in force at zero velocity was observed in the current study, which could be related to recovery practices utilised. Normal recovery protocols were adhered to, with ice baths (~12-15°C for 8 mins), massages and recovery boots used post-training and matches throughout the period analysed. This protocol may have aided in the maintenance of NMF and acceleration, however, removal of these protocols would have been inappropriate. Alternatively, a recent investigation suggests improvements in muscle function in the first 72 hours may aid the recovery of NMF, whilst peripheral function (quadriceps potentiated twitch force) may remain decreased for longer [143]. Researchers should look to confirm these findings in a larger population, however, NMF and accelerations do not appear sensitive to periods of fixture congestion.

Examination of subjective daily wellness measures found only sleep hours to be significantly affected (-1.7 hours) between match one and four, with no observed change in sleep quality. Fluctuations in levels of fatigue were observed between matches two and three (-1.7 AU) and three and four (1.6 AU). Recent research in professional rugby league observed player sleep patterns both at home and in a high-intensity two-week training camp [65], with time in bed (ES = -0.72) and total sleep time (ES = -0.92) both moderately decreased throughout the two-week training camp. Further, increased daily training load has been found to be moderately related to changes in total sleep time (r = -0.37) in elite Australian Rules football players [152]. A combination of change in sleeping environment and accumulated training load may have interrupted sleep patterns in the athletes examined. However, the fluctuations in fatigue and minimal change from matches one to four may suggest that although players slept less, the quality was maintained therefore having a minimal effect on perceived fatigue. Further research is required to examine this in a larger sample, however, these findings suggest practitioners should monitor athletes using subjective measures during periods of fixture congestion.

The sample size of the current study is a limitation but the nature of international sport is such that a larger sample was not possible in the given context. However, only players who played successive matches were included for analysis, isolating the effects of successive matches to within player changes, which is a novel analysis in this area. The quality of opposition and score-line were not accounted for, which may further limit the findings of the current study. Finally, the use of recovery modalities may also be considered a limitation of the current study. The nature of international sport means these protocols are used to optimize performance and their control would not provide an accurate representation of what changes are occurring within athletes in these scenarios.

Conclusion

The findings of the current study suggest a decrease in total distance is primarily a result of decreased low-speed running during a period of fixture congestion. This suggests a subconscious strategy to maintain high-speed running actions during a match. Further, it was identified that accumulated loading mostly accounted for these changes in match-running performances, suggesting that back-to-back matches are detrimental to a players' physical output. Lastly, normalized player wellness variables should be tracked during fixture congestion. Importance should be placed on sleep hours, which have been observed to decrease during periods of high loading and may compromise recovery.

Practical applications

It appears from this study that simple GPS metrics, such as total distance and low-speed running, may be sensitive to accumulated loading with further investigation required. Practitioners should look to examine these metrics, in addition to sRPE to provide a better view of changes in player match-running performance. The changes in low-speed running observed, should be examined further as to how tactical and technical qualities are adjusted. Squad rotation should be used strategically to minimize this effect and maximize the opportunity of a positive tournament outcome. Researchers should utilise a statistical method that examines changes within players, as this method may be more sensitive to a period of fixture congestion.

Tracking of subjective measures of wellness may be an important aspect during not just fixture congestion, but during the season in elite sports. Although only sleep hours were observed lower in the current study, changes from day to day may provide a greater insight (e.g. pre- and post-match rather than the day of a match alone). Practitioners should pay attention to sleep hours during periods of high load, where players may become more susceptible to injury due to disrupted sleep patterns and extended recovery kinetics.

Chapter 8: The reduction of match-running in elite female youth soccer players at 2250 m.

This chapter comprises the following paper prepared for International Journal of Sports Physiology and Performance.

Reference: Trewin J, Meylan C, Chang-Tsai M, Manson S, Varley MC, Cronin J. The reduction of match-running in elite female youth soccer players at 2250 m. *Int J Sports Phys Perf.* 2017.

Author contributions:

Trewin J, 80%, Meylan C, 5%; Chang-Tsai M, 5%; Manson S, 5%; Varley MC, 2.5%; Cronin J, 2.5%.

Prelude

It was established previously (Chapters 4 and 5) that altitudes greater >500 m resulted in decreased total distance and low-speed running. In these chapters' data was analysed at an average altitude of 810 m (671-1356 m), with more games played at lower altitudes (~671 m), which may not indicate the greatest change in performance and truly represent the effects of altitude on match-running. Higher altitudes, where physiological changes might be exacerbated, could result in greater "one-off" acceleration or high-speed runs, but repeated sprint activity and aerobic based activities would be challenged. The challenges of utilising a senior national team with consistent opposition and at altitude resulted in the current study analysing a youth national team performance at high altitude. The reader needs to be cognizant that the physiology of U20 players is comparable to senior players, meaning responses to altitude would likely be similar between playing groups. Furthermore, at the time of altitude exposure, three players had already played for the senior team, whilst seven in total have gone on to represent the senior team at the Olympic games since this study. Therefore, we feel reasonably confident that any altitude effects noted in this analysis will be fairly representative of senior players. The purpose of this study, therefore, was to examine the effects of 2250 m altitude on the match-running and submaximal running performance of a female youth soccer team.

Introduction

In 1970, Mexico held the FIFA World Cup when little knowledge about how much physical performance may be affected when playing matches at an altitude between 1500 m and 2600 m. However, it has been demonstrated that endurance performance can be negatively affected from altitudes as low as 580 m, mostly due to the decrease in O_2 saturation, leading to a reduction in VO_{2max} of around 7% per 1000 m of altitude ascended [134]. In soccer, where aerobic based running is interspersed with high-speed anaerobic actions, it could be hypothesized that overall performance could decline due to the significant contribution of the aerobic system to overall match-running performance [153].

Playing at altitude has become common in international soccer, with the FIFA World Cups 2010 and 2014 being played in various altitudes ranging from sea level to 1753 m [39]. In recent years, researchers have examined the performance of soccer players at a range of altitudes (1600-3600 m) in both male and female athletes [11, 38, 41]. It has been reported that aerobic effort, reflected by metrics such as total distance travelled, are decreased by up to 10% compared to that of sea-level performances [11, 38, 41]. Additionally, high-speed running and accelerations were also decreased by as much as 25% [11, 38]. However, whilst providing some valuable information, players who played at sea-level did not necessarily play at altitude due to squad rotation [11, 38] The only study using female athletes observed 12% less total distance at 1800 m of altitude in 6 college aged athletes [41]. This study employed a mixed model statistical approach, to account for match-to-match variation, however, only two games at sea level and one game at altitude were played. Further research is required to expand on these initial studies and provide further insight into the effects of altitude on elite female soccer players.

Analysis of a full match is likely to miss the period of highest match-running, with a rolling analysis shown to provide a more accurate representation of peak running [54]. Peak match-running was observed to meaningfully reduce in elite male youth at 1600 m and at 3600 m [11, 38]. The change in performance between peak running and the 5 mins post has also been shown to increase at altitude [11, 38]. With so many factors likely to affect performance in the post period, match-to-match variation is high making conclusions difficult [128]. The examination of peak running, however, may provide an indication of overall ability to maintain peak match-running. This ability is likely decreased due to O_2

saturation [109, 135], which should be further examined during matches at altitude in elite female soccer players.

Researchers have briefly examined the effects of altitude on match-running, providing initial insight in to possible changes [11, 38, 41]. The consistency in opposition, scoreline, temperature, and pre-disposed tactical behaviors were not controlled in these studies. Furthermore, players were not restricted to having played at sea-level and altitude, with limited matches at sea-level to account for normal match-to-match variation. Finally, only one study has investigated these effects on the female soccer players, who were college level athletes, utilizing a mixed model statistical approach. While addressing these limitations, the purpose was to examine the change in match-running, and heart rate response to a submaximal running test in elite female youth at 2250 m compared to sea-level. This will provide practitioners further understanding of the reduction in match-running expected at 2250 m, leading to improved preparation for matches at altitude.

Methods

Participant data

Players from an Under 20 National Women's team preparing for youth world cups in 2014 (n = 20, age = 18.9 ± 1.1 y, mass = 61.4 ± 5.1 kg) and 2016 (n = 11, age = 18.2 ± 1.3 y, mass = 62.3 ± 4.9 kg) signed informed consent for longitudinal tracking and data analysis, approved by the University of Victoria Human Research Ethics Board. Stability of testing measures throughout the four-year collection period are presented in Table 19. Player movement data was tracked during eight international friendlies spanning four years (2013-2016). Files were included for analysis for players completing a full match half (~45 mins).

Table 19: Fitness test results through the four year collection period presented as mean ± SD.

Year	30-15 ($km.h^{-1}$)	10m (s)	Max Velocity ($km.h^{-1}$)	Countermovement Jump (cm)
2013	19.0 ± 1.1	1.92 ± 0.08	28.5 ± 1.1	33.3 ± 4.3
2014	19.4 ± 1.0	1.93 ± 0.09	29.1 ± 1.2	32.4 ± 3.4
2015	19.5 ± 0.6	1.91 ± 0.05	28.8 ± 1.3	32.2 ± 2.8
2016	19.4 ± 0.8	1.96 ± 0.08	28.5 ± 1.6	32.3 ± 4.5

Table 20: Descriptive data (Mean ± SD) from all games at sea-level and altitude.

		Match 1 2013	Match 2 2013	Match 3 2014	Match 4 2014	Match 5 2014	Match 6 2014	Match 7 2016	Match 8 2016
Files		10	9	9	11	10	11	8	8
Score (Canada first)		1-0	1-1	2-2	1-2	0-0	0-3	0-0	0-2
Opposition		Norway	Denmark	South Korea		Mexico		Mexico	
Altitude (m)		0	0	0	0	2250	2250	2250	2250
Temperature (°C)		19	24	24	25	20	25	22	26
Minutes Played		45.0	48.3	45.4	46.4	45.2	46.1	46.6	50.0
Total distance ($m.min^{-1}$)									
	Match	118 ± 9.7	107 ± 11	121 ± 9.8	123 ± 13	118 ± 13	107 ± 8.9	98 ± 5.1	102 ± 6.5
	Peak	146 ± 9.8	136 ± 13	143 ± 9.6	146 ± 12	141 ± 16	133 ± 10	122 ± 5.9	130 ± 6.5
Low-speed running ($m.min^{-1}$)									
	Match	109 ± 8.7	100 ± 10	111 ± 8.2	113 ± 11	107 ± 11	99 ± 7.8	92 ± 5.6	96 ± 5.9
High-speed running ($m.min^{-1}$)									
	Match	9.0 ± 4.1	7.4 ± 4.0	9.6 ± 3.2	9.7 ± 3.4	11 ± 4.7	7.9 ± 2.3	5.4 ± 2.2	6.2 ± 2.2
	Peak	18 ± 7.1	18 ± 8.6	21 ± 5.6	23 ± 5.2	22 ± 8.4	19 ± 5.9	14 ± 3.5	17 ± 7.0
Accelerations ($Count.min^{-1}$)									
	Match	1.21 ± 0.27	1.10 ± 0.32	1.24 ± 0.38	1.60 ± 0.32	1.24 ± 0.20	1.18 ± 0.23	1.56 ± 0.36	1.48 ± 0.32
	Peak	2.12 ± 0.50	2.13 ± 0.50	2.33 ± 0.66	2.69 ± 0.60	2.26 ± 0.42	2.24 ± 0.47	2.75 ± 0.42	2.55 ± 0.59
PlayerLoad ($AU.min^{-1}$)									
	Match	12 ± 2.2	11 ± 1.7	12 ± 1.1	12 ± 1.4	11 ± 1.9	11 ±1.4	9.5 ± 1.1	10 ± 1.4
	Peak	16 ± 2.4	14 ± 2.4	15 ± 1.0	15 ± 1.5	14 ± 2.2	14 ± 1.9	13 ± 1.8	14 ± 2.0
RPE (AU)									
	Match	6.6 ± 1.1	8.1 ± 0.6	7.1 ± 0.7	6.4 ± 1.1	6.8 ± 1.0	6.9 ± 1.2	8.3 ± 1.1	7.4 ± 0.7

Four matches were played at sea-level (n = 17, Files = 37, Range = 1-4 per player, Minutes Played = 46.2 ± 1.3 mins) and four matches at an altitude of 2250 m (n = 27, Files = 39, Range = 1-2 per player, Minutes Played = 46.8 ± 1.8 mins) in Mexico City (Figure 9). The data set was grouped for two analyses; all files and 2014 files, with 2014 files restricted to players who had competed in at least two sea-level and one altitude match (n = 10, files = 42, Range per player = 3-4, Minutes Played 46.0 ± 1.1 mins). Matches five and six in 2014 were played following one and three-days at altitude, whilst matches seven and eight in 2016 were played following seven- and nine-days. The characteristics, such as opposition, scoreline, and altitude are shown in Table 20.

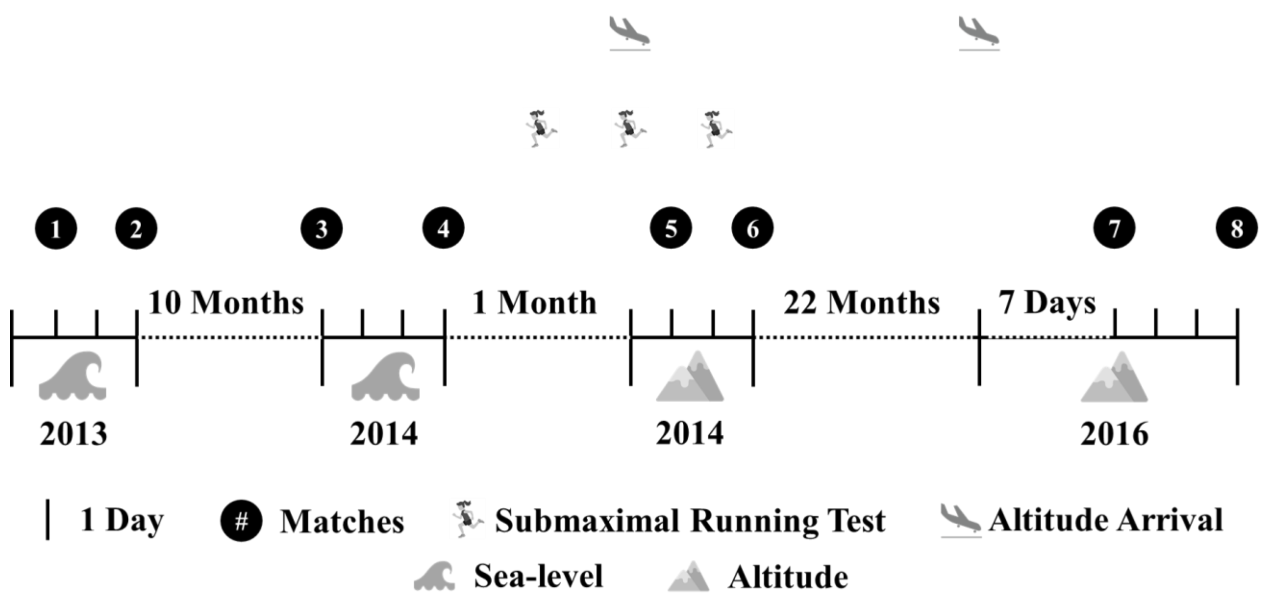

Figure 9: Timeline of study indicating where matches, altitude arrival, and submaximal running tests occurred.

Match analysis

Speed data were collected via GPS technology sampling at 10 Hz (Minimax S4, Catapult Innovations, Australia). An accelerometer and gyroscope sampling at 100 Hz were also coupled with the GPS unit. Raw files were exported from manufacturer software (Sprint 5.1, Catapult Innovations, Australia) and analysed using a custom-built MS Excel spreadsheet [28] (2016, Microsoft, United States of America). Speed was calculated using the Doppler shift method, as opposed to the differentiation of positional data [28], as this method is associated with a higher level of precision [114]. To isolate peak running periods ($Peak_5$), data were analysed using a rolling 5 min period from every sampled time point as distance covered or efforts completed [54]. The mean number of satellites and horizontal dilution of precision for matches were 11.9 ± 0.37 and 0.89 ± 0.02 respectively. The number of satellites and horizontal dilution of precision quantify the quality of GPS data utilised [85].

Movement categories

Player movement categories were defined using previously described locomotor analysis utilised in previous female literature [128]. High-speed running was defined as an effort > 4.58 $m.s^{-1}$, with low-speed running any movement performed at < 4.58 $m.s^{-1}$. Maximal accelerations were defined as an effort > 2.26 $m.s^{-2}$, which represented 80% of a players' mean acceleration over 10 m which was established during piloting. As a player may continue to accelerate at a submaximal rate, an acceleration was defined as beginning once a player exceeded the specified threshold and finishing when acceleration dropped below 0 $m.s^{-2}$ [28]. All speed and acceleration data was calculated using a 0.3 s time interval and presented relative to total match time ($.min^{-1}$). PlayerLoad is a manufacturer metric defined as the sum of accelerations through all planes of movement, taking into account player contact, jumps, accelerations, decelerations and general movements. A strong relationship has been reported between PlayerLoad and total distance covered by athletes ($r = 0.63$-0.74) in soccer and field hockey with a moderate match-to-match variation (CV = 14%) in elite female soccer players [116, 121, 128].

Submaximal testing

A submaximal running test was performed at sea-level and altitude to analyse player heart rate response to altitude at fixed intensity [154]. Players performed a 5'-1' submax test prior to and during 2014 altitude exposure, adapted from previous research, with the testing timeline shown in Figure 9 [154]. The protocol consisted of players running for five minutes at 12 $km.h^{-1}$ over a 40 m shuttle distance. Following the running period, players immediately sat on the ground for one minute, without talking or moving. Heart rate was recorded as the average of the last 30 s of exercise, considered as the player's heart rate at exercise (HRex), and the average of the last 5 s of recovery. The percentage change from exercise to recovery was considered as the player's heart rate recovery efficiency (HRR). All tests followed a similar warm up consisting of dynamic mobility exercises and light running. The typical error

Table 21: Matched analysis Mean ± SD and percentage changes between conditions.

		Sea-level		Altitude		2014		All	
		2013	2014 (%)	2014	2016 (%)	Sea-level	Altitude (%)	Sea-level	Altitude (%)
Total distance (m.min^{-1})	Match	112 ± 12	9.3 (3.3, 15)[1]	112 ± 14	-11 (-16, -4.9)[2]	123 ± 12	-6.7 (-12, -1.1)[1]	117 ± 13	-8.8 (-13, -4.7)[2]
	Peak	141 ± 13	2.9 (-2.1, 7.8)	136 ± 15	-7.9 (-13, -2.6)[3]	145 ± 12	-3.8 (-9.0, 1.1)	143 ± 12	-7.4 (-11, -4.0)[2]
Low-speed running (m.min^{-1})	Match	104 ± 11	8.4 (2.7, 14)[1]	103 ± 12	-8.0 (-14, -2.6)[3]	113 ± 11	-7.3 (-13, -2.5)[1]	109 ± 11	-8.5 (-12, -4.7)[2]
High-speed running (m.min^{-1})	Match	7.9 ± 4.2	22 (-6.5, 50)	9.4 ± 4.2	-38 (-60, -17)[3]	9.7 ± 3.6	1.3 (-22, 24)	8.8 ± 4.0	-11 (-28, 6.4)
	Peak	17 ± 8.2	26 (2.9, 49)[1]	20 ± 7.7	-21 (-42, -0.7)	22 ± 5.8	-4.3 (-14, 22)	20 ± 7.4	-7.3 (-22, 7.1)
Accelerations (Count.min^{-1})	Match	1.1 ± 0.3	29 (11, 47)	1.2 ± 0.2	25 (11, 40)	1.5 ± 0.4	-16 (-29, -3.2)	1.3 ± 0.4	3.7 (-15, 7.4)
	Peak	2.1 ± 0.5	25 (9.1, 31)	2.2 ± 0.4	18 (6, 31)	2.6 ± 0.7	-11 (-24, 1.5)	2.3 ± 0.6	3.8 (-14, 6.0)
PlayerLoad (AU.min^{-1})	Match	11 ± 2.1	7.2 (-1.6, 16)	11 ± 1.7	-7.4 (-16, -1.4)	12 ± 1.4	-9.5 (-17, -2.5)[3]	12 ± 1.8	-11 (-17, -5.9)[1]
	Peak	15 ± 2.3	1.4 (-6.1, 8.8)	14 ± 2.1	-2.7 (-6.6, 12)	15 ± 1.4	-6.9 (-14, -0.1)[3]	15 ± 1.9	-9.3 (-15, -4.2)[1]

[1] = Moderate and very likely different; [2] = Moderate and almost certainly different; [3] = Moderate and likely different; [4] = Small and likely different.

for the measures of interest has been quantified in pilot testing as; HRex was 2.46 bpm (90% CI: 2.03, 3.29), HRR was 7.9% (CI: 6.6%, 10%) and RPE was 0.44 AU (CI: 0.37, 0.56).

Statistical analysis

To analyse data from both conditions, a mixed model and propensity score matching analysis were used. The mixed model was used to analyse the difference between matches at sea-level and altitude in 2014, sea-level matches in 2013 and 2014, all matches and all matches at altitude, and submaximal running tests at sea level and altitude. Separate analyses were performed for all match activities, with altitude used as the fixed main effect, with random effects for the player and for the match included to account for repeated measures. To account for differences in playing groups between years (2013-2014-2016), players were propensity score matched using session rating of perceived exertion and position for comparison of all matches at sea-level and altitude [155, 156].

An inference about the true value of a given effect, based on the uncertainty in relation to the important difference assumed as 0.20 of the deviation between players in a normal match. Inferences were non-clinical, with an effect deemed unclear if the 90% confidence interval (CI) included the smallest important positive and negative differences; otherwise, the effect was deemed clear. Chances of a greater or smaller substantial true difference were expressed quantitatively and calculated using a custom made Excel spreadsheet [132]. These chances were expressed qualitatively for clear outcomes as follows: >25-75%, possibly; >75-95%, likely; >95-99%, very likely; >99%, almost certainly. The magnitude of a given effect was determined from its observed standardized value (the difference in means divided by the between-subject standard deviation). The magnitude was expressed qualitatively as follows: <0.20, Trivial; 0.20-0.59, Small; 0.60-1.19, Moderate; ≥1.20 Large.

Results

Match-running sea-level

Utilizing the propensity matching analysis comparing 2013 to 2014 matches at sea-level (Table 21), very likely less total distance (-9.3%) and low-speed running (-8.4%) were observed in 2013 matches. Specific match comparisons using the mixed model analysis can be observed in Table 22. Likely to very likely less total distance, low-speed running and PlayerLoad were observed between matches in 2013 (ES = -0.88 to -0.59). Total distance and low-speed running were likely to almost certainly greater in 2014 matches, compared to 2013 matches (ES = 0.63 to 1.30). PlayerLoad was almost certainly greater in 2014 matches (ES = 1.39 to 1.53), whilst accelerations were likely greater (ES = 0.57 to 0.93).

Match-running altitude

Utilizing the same propensity matching analysis, almost certainly less total distance (-11%), very likely less low-speed running (-8.0%) and very likely less high-speed running (-38%) were found in 2016 matches as compared to 2014 matches at altitude.

Table 22: A matrix of percentage changes in match-running performance following mixed model analysis.

Match 2	Match 1 TD = -7.3 (-11, -3.2)[2] LSR = -8.2 (-9.6, -6.8)[2] PL = -8.3 (-14, -3.0)[1]		
Match 3	Match 1 TD = 6.1 (1.2, 11)[1] LSR = 6.0 (1.6, 10)[1]	Match 2 TD = 15 (13, 16)[3] LSR = 14 (12, 15)[3] PL = 16 (8.3, 24)[3]	
Match 4	Match 1 A = 26 (4.8, 46)[1]	Match 2 TD = 12 (9.7, 14)[3] LSR = 11 (8.1, 13)[3] PL = 19 (12, 26)[3] A = 23 (-0.8, 47)[1]	Match 3 A = 21 (6.6, 35)[2]
Match 5	Match 3 TD = -7.7 (-12, -3.7)[2] TD_5 = -6.0 (-10, -1.6)[1] LSR = -7.2 (-11, -3.8)[2] PL = -11 (-18, -4.5)[2] PL_5 = -9.1 (-19, 0.7)[1]	Match 4 TD_5 = -4.7 (-9.1, -0.4)[1] HSR_5 = -24 (-38, -11)[2] PL = -14 (-19, -8.9)[3] PL_5 = -13 (-20, -6.6)[2] A = -22 (-31, -14)	
Match 6	Match 3 TD = -16 (-18, -15)[3] TD_5 = -11 (-13, -7.9)[3] LSR = -16 (-17, -15)[3] PL = -19 (-23, -14)[3] PL_5 = -14 (-22, -5.4)[2]	Match 4 TD = -14 (-16, -12)[3] TD_5 = -9.3 (-13, -5.9)[3] LSR = -13 (-15, -11)[3] HSR_5 = -24 (-41, -7.5)[2] PL = -21 (-25, -17)[3] PL_5 = -17 (-24, -11)[3] A = -20 (-32, -8.7)[2]	Match 5 TD = -8.8 (-14, -4.1)[2] LSR = -9.0 (-13, -5.3)[3]

TD = Total distance; TD_5 = Total distance Peak, LSR = Low-speed running; HSR = High-speed running; HSR_5 = High-speed running Peak; PL = PlayerLoad; PL_5 = PlayerLoad Peak; A = Accelerations; A_5 = Accelerations Peak; [1] = Likely different; [2] = Very-likely different; [3] = Almost certainly different.

Match-running 2014

The descriptive data from each match, including files, score, altitude, and temperature are presented as means, standard deviations with confidence limits in Table 20. Matches in 2014, at sea-level and altitude (matches 3-6), were restricted to players who completed a minimum of two matches at sea-level and one at altitude. Specific changes in match running between matches are presented in Table 22. In summary, it was observed that total distance was very likely to almost certainly less in matches at altitude compared to sea-level (ES = -1.76 to -0.76), which was also reflected in changes to low-speed running (ES = -1.96 to -0.29). PlayerLoad was very likely to almost certainly less (ES = -2.26 to -1.05) in games at altitude, whilst accelerations were almost certainly less to very likely greater in matches at altitude (ES = -1.17 to 0.67). Analysis of the $Peak_5$ periods in this time period revealed that total distance was likely to almost certainly less (ES = -1.45 to -0.61) in matches at altitude. PlayerLoad was likely to almost certainly less (ES = -1.95 to -0.87) whilst high-speed running was very likely less (ES = -1.35 to -0.97) in matches at altitude.

Match-running comparison at sea-level vs. altitude

Figure 10 presents the standardized differences with 90% CI in match-running metrics using a propensity matching analysis of all matches, with Table 21 presenting all descriptive data from matched analysis of each condition with percentage changes and 90% CI. At altitude, compared to sea-level, total distance was almost certainly less in the four matches at altitude (-8.8%) and very likely less in 2014 matches at altitude alone (-6.7%), which was reflected in less low-speed running (-8.5- -7.3%). PlayerLoad was very likely less in the four matches at altitude (-11%) and likely less in 2014 matches at altitude (-9.5%).

Submax test

The submax test results are shown in Figure 11, as a raw change from the initial test. Almost certain increases were observed for RPE from sea-level to day one (1.47 AU, CI; 1.07, 1.89) and day three at altitude (1.36 AU, CI; 0.95, 1.78). Very likely higher HRex was observed between sea-level and day one (6.67 bpm, CI; 3.19, 10.2) and sea-level and day three (8.93 bpm, CI; 3.08, 14.8) tests respectively. Whilst HRR was very likely lower from sea-level to day three (-7.0%, CI; -11%, -3.5%).

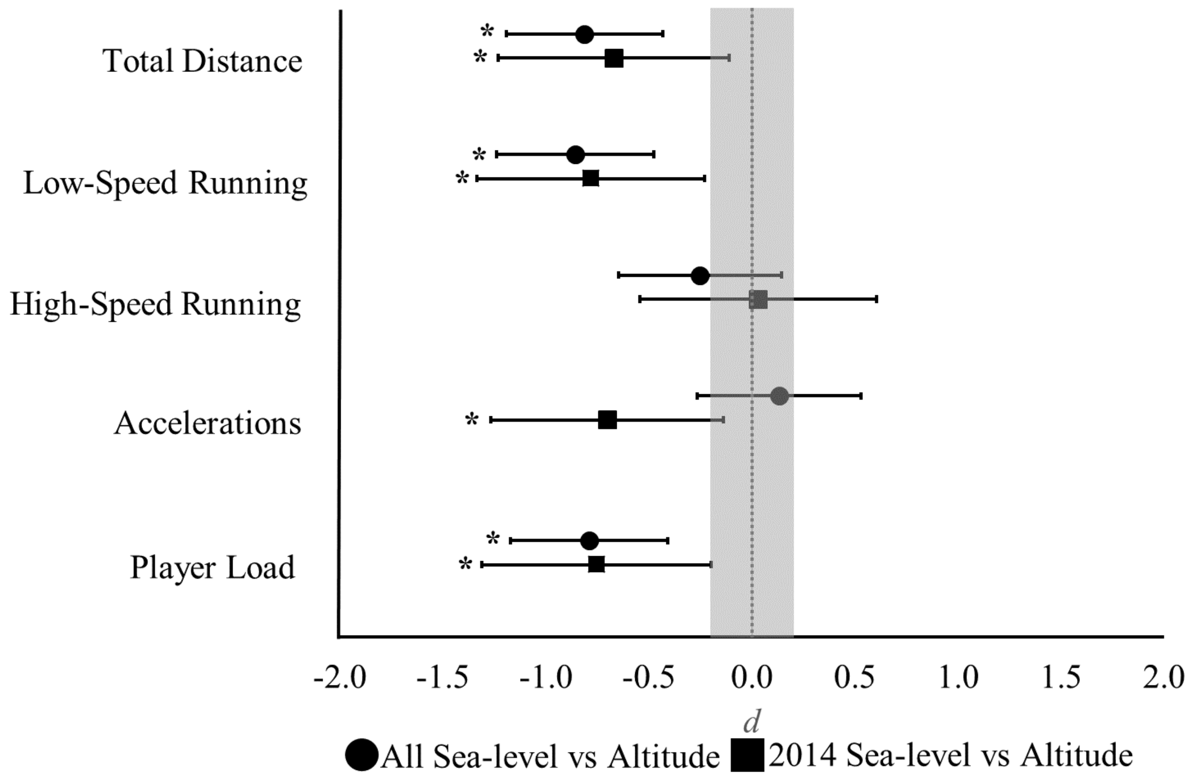

Figure 10: Standardised change in the means of the propensity matched statistical analysis for: All matches at sea-level and altitude (Altitude minus Sea-level); and 2014 matches at sea-level and altitude (Altitude minus Sea-level. * = Moderate change (0.60-1.19).

Discussion

The purpose of this study was to examine the effect of 2250 m of altitude on the match-running performance of elite female youth soccer players. This is the first study to restrict the analysis of altitude to players who had played at least two games at sea-level and one game at altitude. Our findings indicate: 1) a decline in match-running at altitude between matches separated by a day maybe similar to that of matches at sea level; 2) less total distance, low-speed running and PlayerLoad were performed at altitude compared to sea-level, appearing similar to lower-intensity matches at sea-level. 3) less $Peak_5$ total distance is likely at altitude, with no meaningful changes in high-speed running; 4) accelerations appear to be maintained from sea level to altitude; 5) perceived effort and heart rate measures from a submaximal running test increased from sea-level to altitude.

Residual fatigue between matches maybe similar in magnitude at altitude, with an almost identical reduction in match running between matches within two days. A 10% reduction in match-running was observed between match five and six, with an 11% reduction

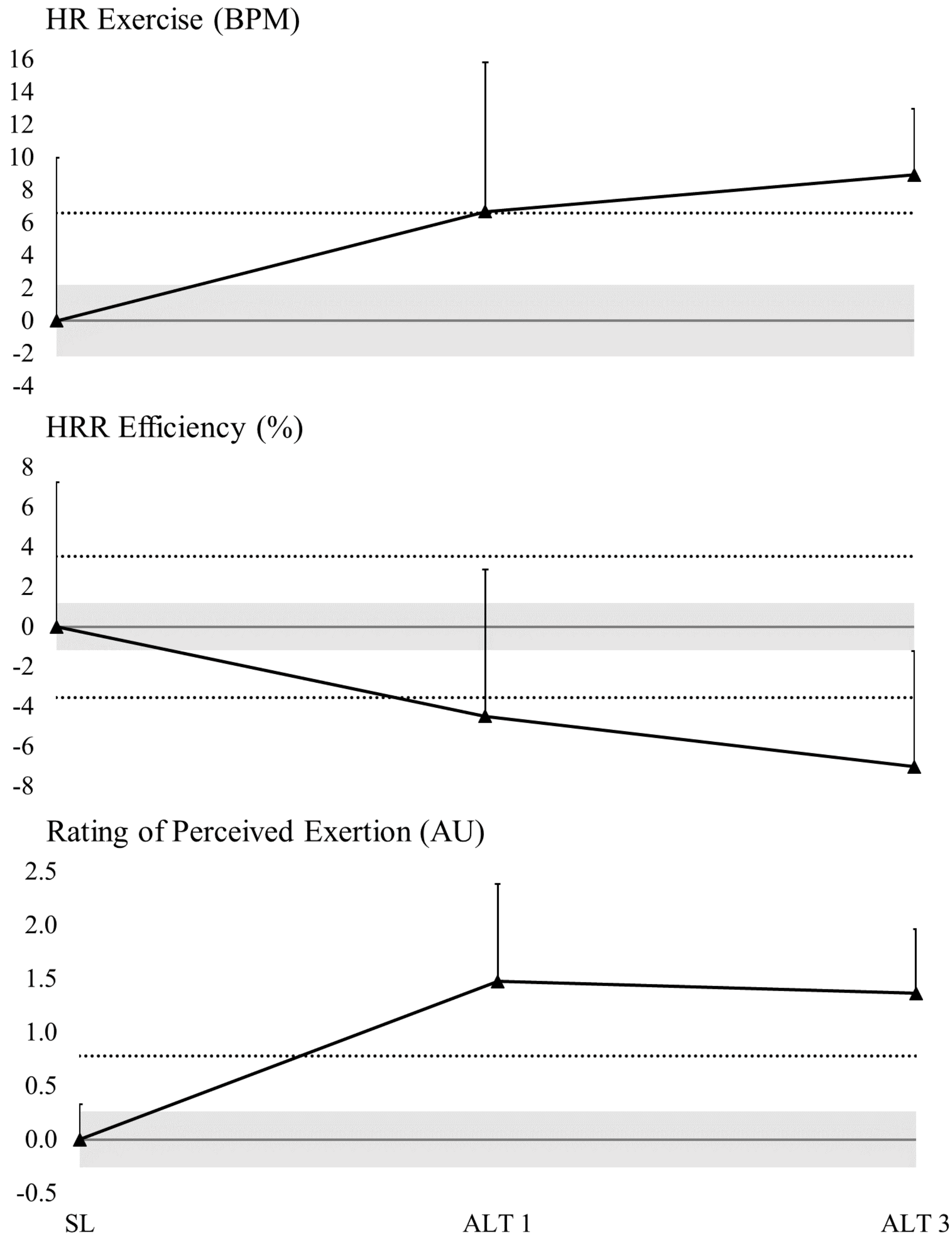

Figure 11: Response to submaximal running test at 2250 m of altitude. Initial test used as baseline, with subsequent tests shown as a change from baseline. The grey area above and below zero indicates the smallest worthwhile change (0.2 x between subject SD from pilot data), with the black dotted line the moderate worthwhile change (0.6 x between subject SD from pilot data). The error bars indicate the SD on each testing occasion. SL = Sea-level; ALT 1 = Altitude Day 1; ALT 3 = Altitude Day 3.

between match one and two. These findings suggest that match-running might be similarly affected between matches at altitude as sea level, particularly where matches are played within one-day. Whilst researchers examining congested scheduling have suggested trivial changes may occur [35, 45, 46], neuromuscular fatigue may be present for ~72 hours [30]. Within these matches, six players started both matches at sea level and altitude. Although not examined, there was a likelihood of neuromuscular fatigue in the starting players due to only ~46 hours between matches. Furthermore, it has been shown that examination of the effects of successive matches should be individualised, as players having different responses to such scheduling [157]. The trend for all players who started both matches highlighted a 4.2-16% decrease in total distance between matches, exceeding that of the typical match-to match variation (CV = 6.8%) for all but two players. Further research is required to examine the change in match running in successive matches, particularly in youth and international soccer where players are more likely to be exposed to multiple matches within 72 hours. The possibility of less total distance between matches should be taken into account by coaches, particularly where squad rotation is limited.

In agreement with previous investigations, less total distance and low-speed running distance, in addition to less PlayerLoad, was associated with playing at altitude compared to sea-level [11, 38, 41]. Interestingly, less movement was also observed in match 6 vs match 5 at altitude in 2014, which contrasts with previous investigations. A previous study in elite male youth observed total distance to be at its least on day one (~9.8%), with no clear effect on day six and day thirteen at 3600 m of altitude compared to sea level [11]. Again in elite male youth, total distance at 1600 m of altitude was still meaningfully decreased following four (-9.1%) and six days (-5.1%) of altitude exposure [38]. The opposite was observed in this study, possibly due to the short 48 h turn around between matches, timing of matches at altitude and limited squad rotation between matches. Furthermore, the second match was lost 3 nil during both exposures to altitude, which may be related to recovery in non-altitude residents at altitude. Less total distance and low-speed running at altitude is likely due to impaired cardiovascular function at these altitudes [88, 108]. The ability of players to perform high-speed running did not appear to be compromised at 2250 m of altitude, this finding supported by other research with the female athlete in this area [41]. Furthermore, the less PlayerLoad, is strongly related to total distance, may be an alternative metric to provide insight into impaired aerobic activity when GPS data is unavailable due to poor signal or enclosed stadia [116]. Further research is required to examine the change in match-running between matches at altitude, with a particular focus on neuromuscular recovery in altitude and non-altitude residents.

The reduction in O_2 saturation and VO_{2max} at altitude may decrease the ability for an athlete to maintain $Peak_5$ match-running [109, 135]. The reduction in $Peak_5$ total distance between sea-level and altitude matches in this study (-4.7% to -11%) was similar to that of research in male youth (-5.7 to -14%) [11, 38]. However, it should be noted that sea level games may experience $Peak_5$ similar to that at altitude, with 2.2% less total distance $Peak_5$ noted between match two and six. Using the $Peak_5$ analysis, a meaningful change (-24%) was observed in $Peak_5$ high-speed running between sea-level and altitude in this study. Researchers have shown a reduction in high-speed running $Peak_5$ is possible [38], however, it appears that more data is required to strengthen the certainty of this change. These changes may be affected by tactical requirements or match situations [11], however, practitioners should be aware of the decreased $Peak_5$ Total Distance likely at altitude. This may have an impact on the tactical approach, with careful planning of pressing or high tempo periods at altitude required. This analysis appears to differ little to that of the full match-analysis, the full match data therefore may be sufficient to identify changes in match running in relation to altitude. However, such an approach is not recommended at sea level to identify the worst-case scenario [9, 54].

The reduction in O_2 at altitude may enhance the ability for an athlete to perform high-speed running and, therefore, accelerate [108]. Soccer researchers [38] have shown a moderate decline in peak accelerations at 1600 m compared to sea-level, and in this study we found a large decline in overall match accelerations between match four and five (ES = -1.21, CI; -1.54, -0.89) and four and six (ES = -1.27, CI; -1.62, -0.93). However, accelerations were not meaningfully different between matches three and five and three and six. It could be possible that submaximal performance is altered to allow the maintenance of maximal performances (such as accelerations) where required throughout a match [11]. Overall match-running has been reported similar between playing formations, however, accelerations were not included and should be examined where possible [19]. Particularly, where a team sets up to defend, which is a likely approach to limit the effects of altitude. Practitioners should be aware that although total distance is decreased, the post match neuromuscular fatigue may be increased compared to a sea-level match. This is particularly important as the match may be more anaerobic in nature at higher altitudes [158], due to increased heart rates as a result of decreased oxygen saturation. Whilst not examined directly, HRex was greater during the submaximal running test at altitude, which may also indicate a greater amount of internal load during matches.

The monitoring of a submaximal running test highlighted an increase in RPE (ES = 2.10-2.70) and HRex (ES = 0.70 to 1.26) with a decreased HRR (ES = -1.06 to -0.61) when performed at altitude as compared to sea level. An examination of elite male youth soccer players[154] reported increased heart rate (ES = 1.9-2.1) during a submaximal test, consisting of 5 mins running at 9 $km.h^{-1}$. Meanwhile, RPE following completion of the submaximal test, returned to baseline within two days of altitude residence. This finding differs from that of this study, which observed an increase in RPE from day one to day three of altitude residence, however, this may be related to increased fatigue from the match a day prior. Hypoxia has been shown to affect perceived exertion during an incremental cycling test at a range of altitudes [159]. The increased perceived exertion is likely in response to lower blood oxygen content during exercise at altitude [160]. This type of submaximal testing has potential in the monitoring of athletes at altitude to examine and identify changes in performance. This test may also be sensitive enough to identify when an athlete has acclimatized to altitude.

Due to the nature of applied research, the reader needs to be cognizant of a number of limitations. In an effort to control for limitations of previous research, consistency with temperature and opposition played mean these factors were unlikely to have an effect on the changes observed at altitude. By including 2014 players who played two matches at sea level and one match at altitude, this has strengthened the findings of the paper compared to previous research [11, 38, 41]. However, the 2016 group had no games at sea level to compare so we attempted to control for this using a novel matching analysis, whereby players were matched by position and sRPE for analysis. The changes reported cannot be isolated to altitude and may be an effect of the different players in each group, the 2016 results therefore should be interpreted with caution. The nature of elite youth friendly matches resulted in up to six substitutions occurring within a match, which is something we were unable to control. We, therefore, limited the current analysis to only a full match half, which may not provide the full picture of the change in match-running that is occurring, with second half performances possibly further decreased. Further analysis utilizing full game players would help to identify if the change between halves is greater than that at sea level.

Match-running performance is affected at altitude, with total distance, low-speed running and accelerations all decreasing. Whilst RPE upon completion of a submaximal running test also increased during altitude exposure, highlighting an alternative to technology in examining the internal response to a standardized external load. These findings expand that already understood in male literature, with similar trends reported.

Practical Applications

The greater anaerobic contribution to match-running at altitude means practitioners should alter carbohydrate loading protocols. In particular, within match intake of carbohydrates should be increased where possible, as the pre-match intake of carbohydrate may already be at a near maximal level. When matches at altitude will be played within 48hours, recovery should be maximised through increased carbohydrate intake post-match, with active and passive recovery protocols strictly enforced. In addition, practitioners might look to utilise a submaximal running test to monitor a players' response to altitude. This method may assist monitoring player acclimation, with further research required to confirm this.

Coaches should consider their tactical approach to a match at altitude, particularly through modelling the individual response to altitude of all players. Through this approach, coaches can pick a team best suited to performance in the expected conditions of the match. Furthermore, coaches may look to utilise a defensive formation (4-5-1 or 5-4-1) at altitude, in an attempt to limit overall movement of players and maintain defensive stability. However, this may result in greater high-speed running in an attempt to reach an attacking position. Coaches should therefore utilise slow build-up play to limit high-speed running and maintain anaerobic energy sources.

Section 4: Application of match-running data to training load examination

Chapter 9: An examination of training load and readiness during five-weeks preparation for two international tournaments in international female soccer players.

Chapter 9: An examination of training load and readiness during five-weeks preparation for two international tournaments in international female soccer players.

This chapter comprises the following chapter prepared for Science and Medicine in Football

Reference: Trewin J, Meylan C, Chang-Tsai M, Varley MC, Cronin J. An examination of training load and readiness during five-weeks preparation for two international tournaments in international female soccer players. *Sci Med Football*. 2017.

Author contributions:

Trewin J, 82.5%; Meylan C, 5%; Chang-Tsai M, 5%; Varley MC, 5%; Cronin J, 2.5%.

Prelude

The analyses in this thesis have provided a strong overview of match-running in elite female soccer players. Practitioners typically utilise match-running data to inform training protocols and loads to prepare for these matches. Due to inherent match-to-match variation (Chapter 3) and match-factors that might be present (Chapters 4 and 5), examining the effects of a training intervention on match-running is challenging. Therefore, the following study examined a preparatory phase guided by the principles of match-running that players are likely to be exposed to within a tournament phase. This approach was taken to highlight how the results of this thesis was utilised within a high-performance environment to optimally prepare players for an international tournament, where the team finished sixth (Women's World Cup) and third (Olympic Games). Typical periodisation theory suggests a period of building towards a higher volume, maintaining that volume for a period prior to a taper, or reduction in the volume whilst maintaining or increasing intensity. The preparation for pinnacle tournaments may see teams together for four to six weeks, providing little opportunity for the application of typical periodisation theory. Within the event, players may experience a total external load exceeding 30 km within seven-days, equating to approximately three games, in either training or match-play. In addition, the forecasting and approach for each training session were based around preparing players for the total and $Peak_5$ loads identified in this thesis. In addition to loading, research has shown periods of increased load may affect a range of perceived wellness variables. These variables provide a subjective view of how training may affect player well-being and readiness to perform. To date, reporting of these variables has not been included in training load studies, whilst the change in wellness during the different periodised phases has not been examined. Elite female soccer has two international tournaments within the space of one year, the World Cup and Olympic Games. The purpose of this study was to examine the preparation for two international tournaments in an elite female soccer team, utilising GPS, heart rate, ratings of perceived exertion and perceptual wellness ratings.

Introduction

International events (e.g. FIFA World Cups) and professional seasonal club soccer (e.g. English Premier League) offer different challenges in terms of physical preparation and load management. During a club season, physical preparation is mostly conducted during the off and pre-season while the in-season focuses on load management, match readiness or player wellness, with acute doses of fitness training [60]. In an international tournament, matches are congested in a relatively short window and typically teams only have two to four weeks to be ready for such a pinnacle competition. Researchers have explored seasonal training load in professional soccer [60, 61], yet very little has been conducted in the preparation to a major international tournament. Club teams generally follow calendar weeks, with a match every seven days, a national team may only be together for short blocks of around 10-days. Further, matches may be as little as 72-hours apart, therefore, acute compared to medium term loading may provide a better indication of training stress in international environments.

Typically, periodisation theory suggests a period of building load, through increased volume of running prior to a reduction in this load prior to competition [62, 63, 161]. Maintenance of frequency and intensity in addition to a 41-60% reduction in volume, over a period of approximately two weeks, have suggested to be optimal for performance following a taper [62, 63]. The goal of preparation for a international tournament is to optimise loading through building resilience and maintaining player freshness, so players are at their physical peak during competition [162].

To optimize tapering and peaking, various tools to measure the training load stress response should be implemented and the quantification of internal and external load has become commonplace in elite soccer environments [8, 60, 61]. External load, referred to as distance covered and distance covered at various speeds, can be monitored using global positioning system technology (GPS) or semi-automatic camera systems [1]. Internal load is monitored via heart rate tracking or ratings of perceived exertion (RPE) and represents the physiological response to an external load [1]. These systems are commonly used in combination to measure the dose-response relationship between the training prescribed and the resulting adaptations [163]. Distance measures alone are unlikely to provide any dose-response relationship in intermittent team sports, whereby internal training load is required [164]. Furthermore, these systems may assist in minimizing soft tissue injury risk during both training and match situations [76].

Whilst, an objective measure of training load provides quantification of loading, the monitoring of athlete wellness through subjective questionnaires has been reported as an effective method to monitor the stress-response to a training program [146]. During periods of high training load, total sleep has been observed to decrease in professional rugby league players [65]. Whilst, measures of fatigue, sleep quality and soreness have been reported as a more sensitive method than heart rate derived measures to the daily fluctuation in session load in elite soccer players [165]. Furthermore, ratings of fatigue have been shown to be sensitive to the acute accumulation of high-speed running distance in elite soccer players [64]. Therefore, during a period of higher training load, such as preparation for an international event, a range of wellness variables are likely to be affected, which has been shown to improve following a taper in a variety of individual and team sports [146].

Training load analyses have focussed on elite male professional teams throughout a season [60, 61], but literature on the elite women's game is scarce. In addition, the analysis of training loads leading in to pinnacle international events, such as world cups or Olympic games, has not been examined in either sex. The purpose of this study therefore was to examine the training load and perceived wellness of elite female soccer players during the preparation phase for international tournaments. The secondary aim was to examine the delay between the exposure to a training load and the response observed in subjective measures of perceived wellness response, over an acute three or fourteen day rolling period. This information is important to identify the methods utilised to examine the effectiveness of a training programme through training load undulation and perceived player wellness.

Methods

Participants and data collection periods

Elite female soccer players from the same senior national team provided informed consent for longitudinal tracking and data analysis, with the study approved by the University of Victoria Human Research Ethics Board. Players were involved in either the 2015 Women's World Cup (WWC; n = 18) or the 2016 Rio Olympic Games (OLY; n = 16), or both (n = 9), with player characteristics presented in Table 23. Players belonged to the following positional groups for WWC; forward (n = 5), midfield (n = 6), fullback (n = 3) or centre back (n = 4) and for the OLY; forward (n = 5), midfield (n = 4), fullback (n = 4) or centre back (n = 3).

Goalkeepers were excluded due to the different movement patterns and training these players completed.

Table 23: Player characteristics (mean ± SD) from both Women's World Cup (WWC) and Olympic (OLY) preparations.

Characteristics	WWC	OLY
n	18	16
Caps	67.9 ± 53.2	80.8 ± 73.9
International longevity (y)	7.0 ± 4.6	6.8 ± 5.3
Age (y)	26.7 ± 4.8	25.8 ± 5.9
Height (cm)	168 ± 6.2	167 ± 7.3
Weight (kg)	64.8 ± 5.4	63.5 ± 5.6
Skinfolds (mm)	80.4 ± 11.4	90.2 ± 14.1
30-15 IFT ($km \cdot h^{-1}$)	20.2 ± 0.8	20.3 ± 0.7

Training design

Figure 12 depicts the training blocks used in preparation to both events, highlighting training days, matches, travel days and time zone changes. Prior to commencement of each preparation block, players were given a period of regeneration in their home environments for seven to nine days following completion of their club commitment, or a heavy training block if non-professional. Each preparation was split into three distinct blocks: a training block emphasis, a friendly match block and a taper block. Each block for OLY was 12, 10 and 10-days in length respectively, whilst the blocks were 14, 8 and 7-days respectively for the WWC.

During the WWC preparation, two closed-door friendly matches were scheduled within the training block (Day -24 and -23; squad rotated), followed by a 7-day heat acclimation camp (5 sessions) in Cancun, Mexico (>30°C). In the OLY preparation training block, no friendly matches were scheduled, with an intra-squad match played instead (Day -24). The friendly match blocks did not differ in structure, with the first match played behind closed doors and the final friendly being an A international. As shown in Figure 12, the main difference between preparations was jetlag management during the friendly block of OLY preparation. The taper slightly differed as the OLY preparation had a greater regeneration period, to then resume training, following jet lag management. Finally, strength maintenance had a greater emphasis in the OLY preparation, with a resistance training session scheduled at least every five to nine days (up to Day -7), whereas the last resistance session occurred Day -28 before the first game of the WWC [166].

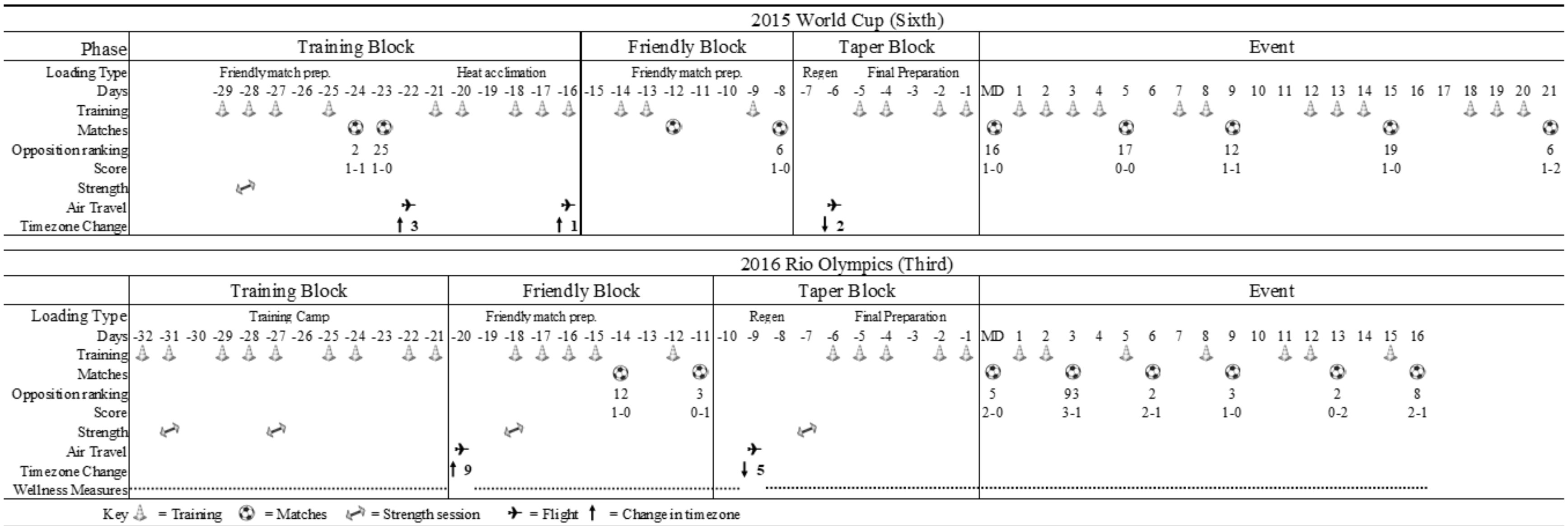

Figure 12: Figures of the preparation for each International tournament. Scores shown with reference team first. Opposition rankings taken from rankings reported immediately prior to the tournament.

Each block of training was strictly planned utilizing historical data to estimate the "ceiling" and "flooring" of training load volume for a seven day micro cycle, with the principle of acute:chronic workload ratio in mind [50]. Ultimately, competition load was set as the objective to build towards and reference to match load was used to provide an insight into relative training load [5]. Differences in training design were present following staff reflections of WWC preparations, with OLY requiring a greater training load accumulation to provide players with the ability to handle the congested nature of an OLY tournament (Figure 12).

Data analysis

External load, or player movement data, was collected via global positioning system technology (GPS) sampling at 10 Hz (Minimax S4, Catapult Innovations, Australia). Data were analysed using manufacturer software with a generic report created for each training session and match (Sprint 5.1, Catapult Innovations, Australia). Movement was categorised as distance in total and efforts within the high-speed running band (>16.5 $km.h^{-1}$). This band was selected based on previous female literature and set utilizing locomotor based guidelines outlined in male youth [24, 99, 128]. Manufacturer PlayerLoad™ was captured utilising a 100 Hz accelerometer and gyroscope coupled with the GPS unit. PlayerLoad represents a sum of accelerations through all planes of movement, which may account for jumps, short explosive actions or player-to-player contact. Where a player's data was missing, through either not wearing a unit or other means, either a training session team average or player norm for approximate minutes played were used [8].

Internal load was monitored via heart rate monitors (Team2, Polar, Finland) with total load calculated using the Edwards training impulse (TRiMP) method [59]. Meanwhile, RPE was collected from all players using a modified Borg scale (1-10), which has been utilised in previous research [57-59]. The rating received from players was then multiplied by duration to obtain session-RPE (sRPE). All data was stored using MS Excel (2016, Microsoft, United States of America) and utilised for statistical analysis.

Perceptual ratings of wellness were collected during the 2016 Rio Olympic Games. Upon waking up in the morning, players filled out a custom questionnaire utilizing a 10-point Likert scale, with 1 and 10 representing a negative state of wellness and a positive state of wellness respectively. Players were asked to rate their fatigue, sleep quality, stress perception, training progression and soreness, with the value from each summed to give an overall wellness score.

Statistical analysis

The days leading up to the international tournaments were categorized into three phases (training, friendly and taper block), with daily training loads (sRPE, TRiMP, total distance, high-speed running efforts and PlayerLoad) and wellness measures (fatigue, sleep quality, stress perception, training progression and soreness) averaged for each phase, including rest days. A one-way repeated measures ANOVA mixed model was used to test for training load and wellness differences between each and within preparation. Data were presented as means and standard deviations.

To measure the correlation between time series, daily training load (1-, 3-, 7-, 10-, 14-day rolling averages of sRPE, TRiMP and total distance) and wellness questions, a cross-correlation analysis was used with different lags for each player. A one-way repeated measures ANOVA mixed model was used to test for differences in lags between different average training loads. Tukey post hoc analyses were used to identify the differences ($p < 0.05$) in training load rolling periods in relation to wellness delay.

To analyse the magnitude of a given change in training load or wellness, an inference about the true value of the effect, based on the important difference assumed as 0.20 of the standard deviation between players for a given metric, was utilised. Inferences were non-clinical, with an effect deemed unclear if the 90% confidence interval (CI) included the smallest positive and negative differences; otherwise, the effect was deemed clear. Chances of a greater or smaller substantial true difference were expressed quantitatively and calculated using a custom-made Excel spreadsheet [132]. These chances were expressed qualitatively for clear outcomes as follows: >25-75%, possibly; >75-95%, likely; >95-99%, very likely; >99%, almost certainly. The magnitude of a given effect was determined from its observed standardized value (the difference in means divided by the between-subject standard deviation). The magnitude was expressed qualitatively as follows: <0.20, Trivial; 0.20-0.59, Small; 0.60-1.19, Moderate; ≥1.20 Large.

Table 24: Daily average and block sums as absolute and relative to match (mean ± SD) normative loads throughout blocks of both the Women's World Cup (WWC) and Olympic (OLY) preparation periods.

	WWC		OLY	
	Daily Average (% of Match)	Block Sum (% of Match)	Daily Average (% of Match)	Block Sum (% of Match)
Total Distance (m)				
Training Block	3730 ± 621	52226 ± 8697	4615 ± 565[2]	55385 ± 6775
	(36 ± 5.9)	(502 ± 83)	(44 ± 5.8)	(533 ± 69)
Friendly Block	2967 ± 1002	23740 ± 8013	3291 ± 686	32907 ± 6863
	(29 ± 9.9)	(229 ± 79)	(32 ± 6.5)	(316 ± 65)
Taper Block	2278 ± 576	15945 ± 4034	2232 ± 394[2]	22322 ± 3939
	(22 ± 5.3)	(153 ± 37)	(22 ± 4.1)	(216 ± 41)
Total Preparation	2899 ± 597	91911 ± 14967	3379 ± 455	110613 ± 14618
	(0.28 ± 5.7)	(883 ± 143)	(33 ± 4.5)	(1065 ± 146)
Tournament	3037 ± 641	66804 ± 14094	3163 ± 940	53774 ± 15982
	(29 ± 6.3)	(643 ± 138)	(30 ± 8.2)	(514 ± 140)
High-Speed Running Efforts (Count)				
Training Block	21 ± 6	298 ± 84	25 ± 5	300 ± 61
	(38 ± 9.2)	(525 ± 128)	(42 ± 7.3)	(499 ± 87)
Friendly Block	18 ± 8	138 ± 64	19 ± 6	191 ± 57
	(30 ± 12)	(238 ± 94)	(32 ± 8.2)	(318 ± 82)
Taper Block	11 ± 4	76 ± 30	15 ± 3[1]	153 ± 32
	(19 ± 6.1)	(133 ± 43)	(26 ± 6.5)	(258 ± 65)
Total Preparation	16 ± 5	512 ± 154	20 ± 4	644 ± 133
	(0.29 ± 7.3)	(896 ± 218)	(33 ± 6.3)	(107 ± 202)
Tournament	16 ± 5	344 ± 101	15 ± 6	260 ± 101
	(28 ± 7.4)	(608 ± 162)	(25 ± 8.6)	(429 ± 146)
PlayerLoad (AU)				
Training Block	408 ± 65	5714 ± 912	489 ± 72	5863 ± 865
	(38 ± 5.8)	(531 ± 82)	(45 ± 6.4)	(539 ± 76)
Friendly Block	307 ± 98	2455 ± 788	344 ± 88	3442 ± 875
	(29 ± 11)	(232 ± 84)	(32 ± 8.0)	(316 ± 80)
Taper Block	262 ± 68	1835 ± 477	246 ± 49[3]	2456 ± 491
	(24 ± 5.9)	(170 ± 42)	(23 ± 4.5)	(227 ± 45)
Total Preparation	326 ± 52	10004 ± 1442	359 ± 60	11263 ± 2735
	(30 ± 5.5)	(933 ± 151)	(33 ± 5.3)	(1036 ± 248)
Tournament	326 ± 70	7176 ± 1539	362 ± 107	6152 ± 1824
	(31 ± 7.2)	(671 ± 158)	(33 ± 8.3)	(560 ± 141)
sRPE (AU)				
Training Block	434 ± 57	6079 ± 804	475 ± 65[4]	5700 ± 777
	(60 ± 9.2)	(837 ± 128)	(69 ± 9.4)	(825 ± 113)
Friendly Block	223 ± 68	1716 ± 603	291 ± 57[1]	2909 ± 575
	(30 ± 8.9)	(234 ± 80)	(42 ± 8.1)	(420 ± 81)
Taper Block	171 ± 48	1194 ± 337	198 ± 43[1]	1979 ± 428
	(23 ± 7.0)	(164 ± 49)	(29 ± 6.2)	(286 ± 62)
Total Preparation	273 ± 37	8989 ± 1071	321 ± 40	10588 ± 1324
	(38 ± 5.0)	(1236 ± 167)	(46 ± 5.8)	(1531 ± 190)
Tournament	244 ± 49	5379 ± 1078	228 ± 60	3871 ± 1022
	(33 ± 5.8)	(734 ± 128)	(33 ± 8.0)	(557 ± 136)
TRiMP (AU)				
Training Block	175 ± 48	2454 ± 668	217 ± 29[5]	2607 ± 350
	(43 ± 11)	(597 ± 152)	(53 ± 7.0)	(642 ± 84)
Friendly Block	104 ± 49	829 ± 393	156 ± 42[6]	1561 ± 422
	(25 ± 11)	(201 ± 91)	(38 ± 8.7)	(381 ± 87)
Taper Block	106 ± 23	745 ± 164	88 ± 28[4]	884 ± 278
	(26 ± 6.4)	(184 ± 45)	(22 ± 6.3)	(216 ± 63)
Total Preparation	128 ± 32	4027 ± 1000	154 ± 28	5053 ± 898
	(31 ± 7.2)	(981 ± 226)	(38 ± 5.8)	(1238 ± 184)
Tournament	144 ± 28	3164 ± 614	153 ± 30	2605 ± 515
	(35 ± 7.1)	(774 ± 156)	(38 ± 7.7)	(642 ± 132)

[1] Large and almost certainly different to WWC; [2] Large and very likely different to WWC; [3] Small and possibly different to WWC; [4] Moderate and likely different to WWC; [5] Moderate and very likely different to WWC; [6] Moderate and almost certainly different to WWC.

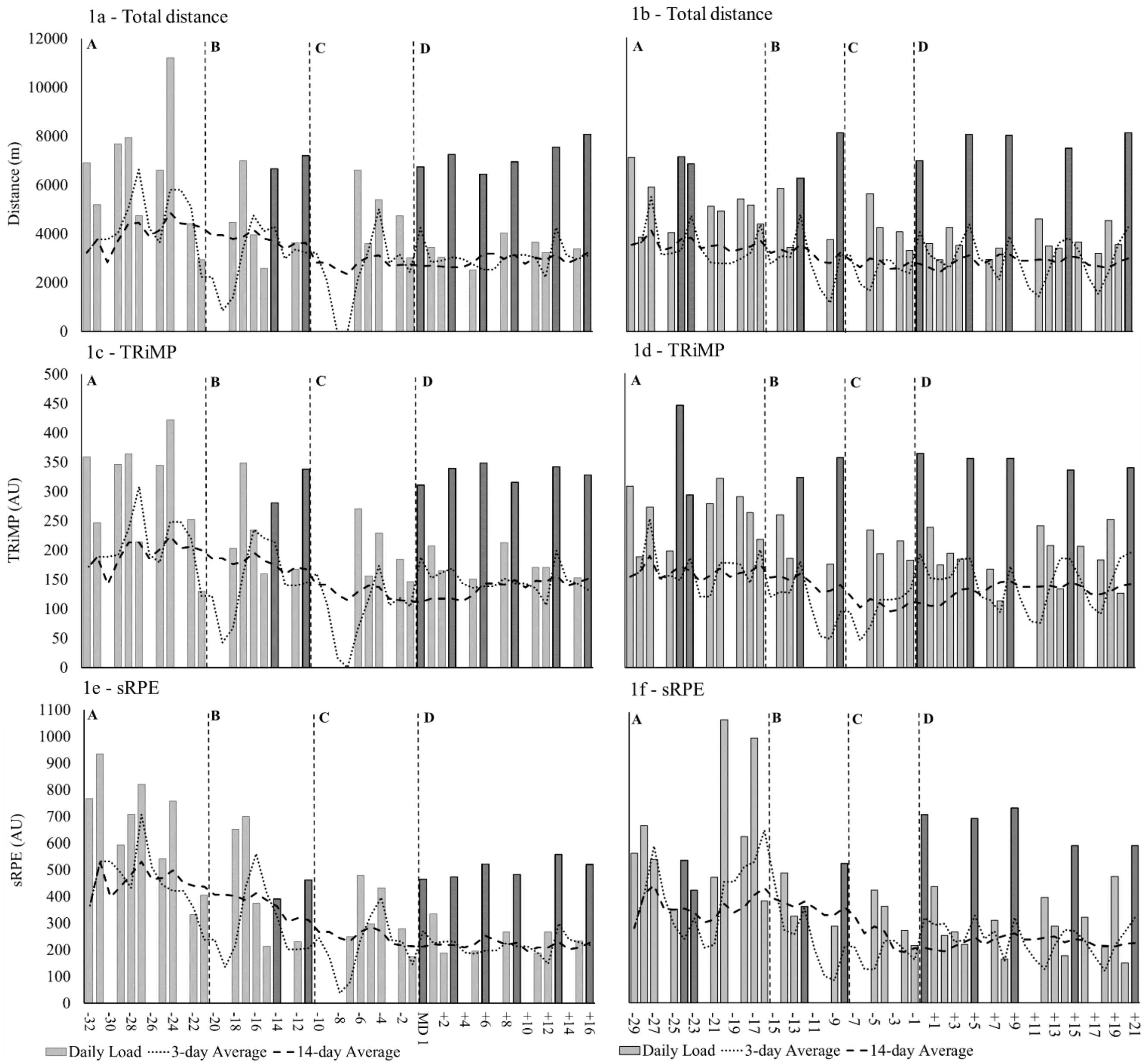

Figure 13: Comparison of loading between OLY (a, c and e) and WWC (b, d and f) phases showing: A = Training block; b = Friendly block; C = Taper block; D = Tournament. Matches are represented by a ■ coloured bar. MD 1 = the first match of the tournament phase.

Results

Training load

The daily average and sum of training load metrics can be observed in Table 24, and the daily training load, in addition to the three- and 14-day rolling averages throughout each preparation in Figure 13. Comparison of daily average training load between block within each preparation indicated the training block to be almost certainly higher for all metrics compared to the taper block (ES = -2.59 to -5.92) for both WWC and OLY. The training block was very likely to almost certainly higher compared to the friendly block (ES = -0.66 to -3.64). The friendly block was likely to almost certainly greater than the taper block (ES = -0.82 to -1.96). When daily average training load was compared between preparation periods, the training block resulted in very-likely greater TRiMP (32 AU, CI; 11, 53) and PlayerLoad (70 AU, CI; 26, 115), and almost certainly greater total distance (808 m, CI; 458, 1158) during the OLY campaign compared to the WWC campaign. The friendly block resulted in certainly greater sRPE (80 AU, CI; 46, 113) and almost certainly greater TRiMP (46 AU, CI; 27, 64) during OLY preparation compared to WWC. The taper block was associated with very likely greater sRPE (53 AU, CI; 13, 92) and high-speed running efforts (4.6 efforts, CI; 1.9, 7.3) during OLY preparation compared to WWC preparation.

Wellness

The examination of wellness with respect the preparation blocks can be observed in Table 25 and Figure 14. During the taper block compared to the friendly block, all wellness scores were likely to almost certainly improved (ES = 0.59 to 2.55). During the taper block compared to the training block, all wellness scores were very likely improved (ES = 1.26 to 1.65), with the exception of training progression, which was unclear. All differences between the training block and friendly block were unclear, with the exception of stress perception, which was likely less (ES = 0.59).

Wellness delay

A delay of 0.94 and 2.69 days was observed between total distance covered each day and the reporting of a change in wellness metrics for all wellness variables. When compared to rolling training load averages, the delay was most similar between one-day and a three-day rolling average for fatigue (0.13 days, P = 1.00) and soreness (0.31 days, P = 0.97) but differed for stress perception (0.38, P = 0.97) and training progression (-0.50 days, P = 0.94) with a ten-day rolling average being more similar and a fourteen-day rolling average for sleep quality (0.25 days, P = 0.99). When daily load was expressed as sRPE, the delay was between 0.88 and 2.31 days. The delay between rolling averages was most similar between one-day and three-days for fatigue (0.00 days, P = 1.00) and soreness (-0.06 days, P = 1.00); ten-day rolling average for sleep quality (-1.00 days, P = 0.50); and fourteen-day rolling average for stress perception (-0.06 days, P = 1.00) and training progression (0.13 days, P = 1.00). When daily load was expressed as TRiMP, the delay was between 1.00 and 2.63 days for all variables. The delay between different rolling daily averages was most similar between one-day and three-days for fatigue (0.00 days, P = 1.00), sleep quality (-0.19 days, P = 1.00); seven-days for training progression (-0.31 days, P = 0.99) and soreness (-0.50 days, P = 0.90); and fourteen-days for stress perception (0.06 days, P = 1.00).

Table 25: Wellness data mean ± SD in relation to each training block.

Wellness Variable	Training Block	Friendly Block	Taper Block	Tournament
Fatigue	6.84 ± 0.80	6.92 ± 0.81	7.37 ± 0.77[1, 2]	7.30 ± 0.83
Sleep Quality	7.38 ± 0.88	7.14 ± 1.10	7.59 ± 0.88[2, 3]	7.46 ± 0.95
Stress Perception	7.59 ± 0.79	7.61 ± 0.68	8.11 0.79[2]	7.76 ± 0.91
Training Progression	7.24 ± 0.76	7.25 ± 0.80	7.55 ± 0.64[1]	7.70 ± 0.61
Soreness	6.72 ± 0.91	7.20 ± 0.67	7.42 ± 0.81[1, 2]	7.39 ± 0.93

[1] = Large and almost certainly different to friendly block; [2] = Large and very likely different to training block; [3] = Moderate and very likely different friendly block.

Discussion

The purpose of this study was to examine the training load of players during preparation for two international tournaments and its effect on perceived wellness during the preparation for a one-off event. The main findings from the statistical analyses were: 1) meaningfully different training loads were observed when comparing blocks of periodisation between and within events, highlighting the specificity of training for different tournaments; 2) where average training load was highest, wellness was lowest, with the taper effective in improving player wellness state, strengthening the need for wellness measures to be tracked longitudinally; 3) cross-correlation analysis of wellness and training load brought attention to the possible delay between a change in training load and player wellness response, furthering the importance of individualized training loads and recovery protocols.

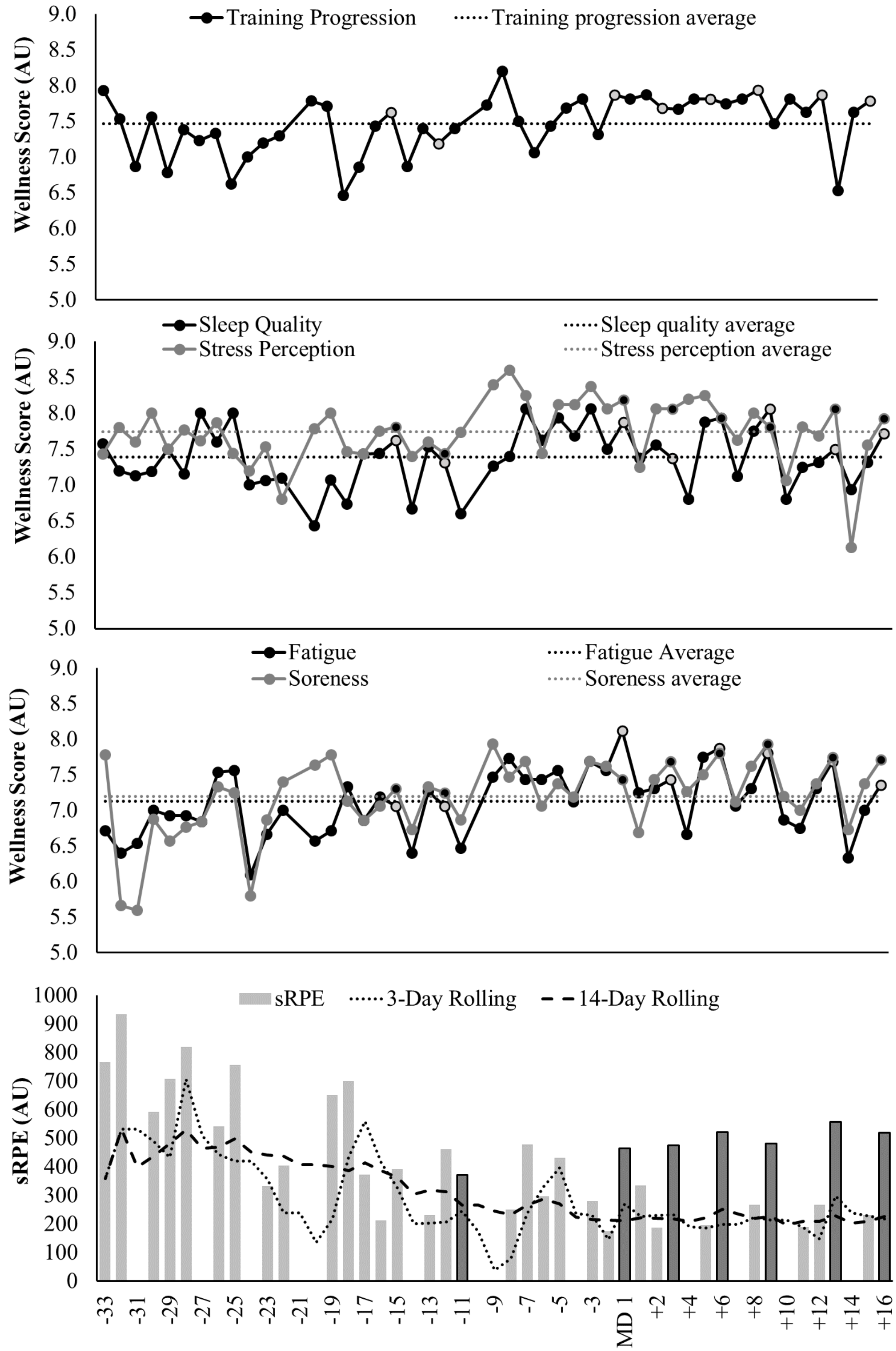

Figure 14: Comparison of sRPE and wellness variables through preparation for the 2016 Olympics. Matches are represented by a coloured circle and averages represented by dotted lines. MD 1 = The first match of the tournament phase.

The training load between events was significantly different, particularly during the training and taper blocks of preparation. It should be noted, the younger average age of the OLY squad, in addition to the condensed OLY tournament led to a change in training design. This design change led to greater training loads to enhance the physical capacity of players to enable them to handle the competition congestion. Almost certainly higher total distance was covered during the OLY training block, in addition to likely higher sRPE, compared to the WWC block. The structure of the training block during WWC preparation reflected a lower accumulation of total distance. Although this block was four days longer, the short-term heat acclimation protocol and closed-door friendlies may have lowered the total distance daily average. The period of heat acclimation may, however, have induced greater RPE response albeit with reduced external load. To examine this, practitioners should look to include an RPE:m/min ratio, which has been suggested as a method of analysing player acclimation to the heat [167]. Furthermore, it should be noted that the daily average training load during each tournament was comparable to that of the total preparation period (Table 2). However, it is likely that starting players had a greater average daily training load, highlighted by the large SD for the competition phase (Table 2), with the need for squad rotation to aid in the recovery of players, particularly during congested tournaments such as the OLY or WWC.

Researchers have suggested a taper of one- to two-weeks as the optimal length with a 41-60% reduction in training volume being suggested during a taper [62, 161]. This is the first study to report a 50% and 38% reduction in total distance between training and taper blocks, and a 30% and 22% reduction between friendly and taper blocks was observed in the OLY and WWC preparations respectively. Alternatively, no significant differences were observed between pre-season training loads in the English Premier League [60].Training load reduction during the OLY preparation lay within or close to the bounds recommended for individual sports [62, 63]. It could be argued that the better results during the OLY campaign (Figure 1) may be attributed to the greater readiness to perform resulting from greater initial training load and more aggressive taper compared to the WWC. However, the optimal training volume and taper for team sports has not been specifically examined, with individual responses to a taper likely present [62, 161]. This study adds to the body of literature on a taper in team sport, with further research required to determine the optimal taper length in team sport athletes. It could be argued that the use of a performance indicator maybe valuable to assess this process in team sport environments, as it can be questioned that current metrics, such as a vertical jump, are reflective of match performance. A performance indicator using practical field metrics [167] have been shown to be promising to track acute fatigue, but still need to be explored further. Practitioners are advised to utilise subjective metrics until further research is completed on field-based metrics relevant to match performance.

A typical training programme is designed to overload an athlete and induce relevant adaptions leading to improved performance, however, this also results in a reversible reduced state of wellness [168]. It can be inferred from examination of data, that where training load was highest during OLY preparation, in both the training and friendly blocks, wellness was at its lowest, the differences between these training blocks unclear. Researchers have shown a decreased state of wellness can occur during an acute increase in training load in trained cyclists and triathletes [169-171]. A taper has been shown to improve wellness in rugby league players [172], however, this is the first study in soccer to observe a likely to almost certain improved wellness through the taper block, compared to both the training and friendly blocks, with maintenance through a tournament period. A taper block has been shown to improve wellness [146], with the taper having been suggested to improve performance in individual sports [62]. Although we did not examine performance, we can confidently report that wellness was at or close to it's peak values on the day of the first match. Therefore, the tracking of wellness variables maybe the most important factor to analysing the effectiveness of a taper period in soccer.

Finally, a novel analysis of training load and perceived wellness was undertaken, and this is the first study to report a possible delay in the player response to a change in training load. The daily wellness with reference to both 3-day and 14-day rolling averages of sRPE can be observed from Figure 3. Correlations between wellness measures and sRPE could be considered small (-0.37 to -0.05). From these findings, it is suggested that practitioners should be aware that a delayed response is possible following training load exposure and structure training appropriately, whilst being aware this response is highly individual. Researchers from the English Premier League suggested that significantly reduced training load was only observed the day before a match [60]. This may not allow player wellness to return towards baseline values, which may result in reduced performance the following day. Strict monitoring of player wellness should be completed within season to manage players who may be required to play in every match.

It should be noted that the following study was limited in that wellness data was only collected during the OLY preparation period. The nature of elite sport means processes are constantly evolving, with new or improved monitoring process being implemented regularly, whilst, objective training load metrics are often largely unchanged. Following the WWC, a review process resulted in a different collection process for all wellness questionnaires to improve compliance in the athletes involved for the OLY.

In summary, significantly greater training load was performed during the OLY preparation period compared to the WWC to assist players with the congested nature of an OLY tournament period, where volume tolerance is necessary. The inclusion of friendlies in the WWC training block, may not have been conducive to building training load capacity. Where tournament congestion requires training load tolerance, preparation for friendlies may not provide players with the sustained period of training the require whilst compromising player freshness. Changes in measures of perceived wellness were inline with that expected during periods of increased training load and improved following the taper. These findings suggest the use of perceived wellness measures maybe all that is required to examine the effectiveness of a training programme, particularly a taper period prior to competition. Furthermore, practitioners should be cognizant of the delay in reporting a change in wellness in response to a training load.

Chapter 10: Summary, practical applications, and future research

Summary

The aim of the thesis was to answer the overarching questions, "What are the effects of environmental and situational factors on player movement in international women's soccer matches?" A secondary aim was to understand "what are the training methods utilised to peak for international tournaments where such variables are in play?" To answer these questions, a thorough review of the literature pertaining to factors affecting movement in soccer was undertaken (Chapter 2). The main findings were that trivial changes in match-running were observed with regards to possession, team formation and match status (win, lose, draw). Match-running was affected by temperatures as low as 21˚C, with both high- and very-high-speed running decreasing (8.5 and 15% respectively), whilst altitude lowers the number of high-speed efforts completed by players (7.1-25%). It appears that environmental factors have a strong influence on the variability and differences observed in match-running performances from match-to-match.

What was apparent from the literature review was that very little research has addressed the factors affecting movement in female soccer players. Improving understanding of the effect of match-factors on match-running in females would allow better planning to minimise possible detrimental factors. Before the effects of these factors could be assessed in elite female soccer, the match-to-match variation of common GPS metrics needed to be examined, in both a full match and rolling peak period analysis (Chapter 3). We found that total distance (CV = 6.8%) and low-speed running distance (CV = 6.5%) were useful measures for detecting changes in movement, while accelerations (CV = 17%) and PlayerLoad (CV = 14%) were observed to have greater variation. The difficulty of using high-speed running distance (CV = 33%), high-speed running efforts (CV = 32%) and sprint efforts (CV = 53%) was reinforced due to the high variability of these metrics. Furthermore, $Peak_5$ periods were found to be similar in variation to the full match analysis, with <3% difference between analyses. $Post_5$ periods were typically highly variable, particularly when examining high-speed running distance (CV = 143%). Following these findings, the ensuing chapters utilised both full match and rolling peak period analyses to examine the effects of selected match-factors on the match-running of elite female soccer players during a full match and $Peak_5$ periods.

The following factors were chosen for simplicity, consistency and impactful application of findings; altitude, temperature, match outcome, opposition rankings, and congested schedules. The effects of the selected match-factors were presented in Chapters 5 and 6, using both a full match and rolling peak period analysis. The findings of the full match analysis highlighted the reduction of total distance (ES = -0.54 to -0.30) and low-speed running (ES = -0.60 to -0.32) at both altitude and in high temperatures. In addition, $Peak_5$ distance (ES = -0.38 to -0.19) and high-speed running (ES = -0.37 to -0.09) were reduced at altitude and in high temperatures, with $Peak_5$ accelerations also reduced in high temperatures (ES = -0.44 to -0.15). Alternatively, varying findings were observed in relation to situational factors, with total distance and low-speed running possibly at their greatest against higher-ranked opponents in a win (ES = 0.60 to 0.67). $Peak_5$ performance across all metrics was greater during the first half of a match compared to second half (ES = 0.34 to 1.05), with a draw associated with greater $Peak_5$ distance and high-speed running compared to a win or a loss (ES = 0.32 to 0.43). These findings highlight the effect of different match-factors that should be accounted for when analysing match-running performances. When temperatures exceed 21°C or altitude is greater than 500 m, specific match protocols should be developed to minimise changes in performance. Furthermore, practitioners should look to prepare their players for the toughest games, which appear to be against higher ranked opponents in wins.

The effects of specific factors in isolation, comparison of substitute and full match players, a congested schedule, and altitude, were then examined in Chapters 6, 7 and 8. Comparison of substitutes highlighted the difference in match-running on a global level, with late substitutes performing a higher rate of total distance (ES = 0.84-0.85), high-speed running (ES = 0.95-1.22) and accelerations (ES = 0.33-0.38), compared to early substitutes and full match players. Currently, these players may perform a shorter session to enhance the anaerobic system, however, a higher volume stimulus may be required if they are needed to complete a full match. In a tournament where only players involved in every game were analysed, we found that total distance (ES = -0.69) and low-speed running distance (ES = -0.76) were meaningfully reduced from game one to four. This change only remained meaningful for low-speed running between games one and two and one and three when the accumulated load was accounted for (ES = -2.97 to -2.08). A moderate decrease in hours of sleep was observed between game one and four (ES = -0.94), whilst no other meaningful changes were observed in player's wellness. From these findings, it might be concluded that accumulated load may play a role in reduced match-running over successive matches, whilst examination of neural fatigue through a jump test may not yield meaningful information. More importantly, the inclusion of player readiness questionnaires should be utilised to identify changes in sleep patterns. When two youth Under 20 teams travelled to 2250 m, total distance and low-speed running were less at altitude compared to sea-level (-7% to -16%). The number of accelerations were almost certainly less at altitude compared to game four at sea-level (-22 to -23%). Peak 5-min total distance was less at altitude compared to sea-level (-5.5% to -11%). HRex (3.7-5.0%) and RPE (43-47%) were greater at altitude compared to sea-level. These findings further reinforce the effects of altitude on match-running, while highlighting a cost-effective method for analyzing acclimation to altitude through a simple submaximal running test and RPE monitoring systems.

Finally, Chapter 9 examined the preparation of an elite female soccer team before two international tournaments. The main findings highlighted the need for practitioners to utilise a wellness questionnaire throughout periods of preparation. Training load metrics highlighted meaningful differences between the Olympic and world cup preparations, particularly during training and taper blocks. Whilst, the training and friendly block were associated with a decreased wellness state. This state of wellness was however improved following the taper block, with players reporting likely to almost certainly better wellness throughout this training period. These findings further support the need for incorporating perceived wellness measures during periods of training.

Based on the evidence presented, common match-factors affect the movement of both an elite senior and U20 female soccer team. However, the examination of these factors in isolation appears problematic due to the chaotic nature of soccer. Practitioners should, therefore, look to analyse these factors in combination where possible. Furthermore, the utilisation of match data to inform training during preparation is of importance. Perceived wellness should be monitored throughout these training periods to examine the effect of these periods on wellness state and the effectiveness of the training programme.

Limitations

The nature of applied research, particularly in the international sporting context, means there are several limitations present within the current thesis:

- Although data was collected over a substantial period, the number of data points were limited, especially in some environmental conditions, such as altitude. The nature of elite international soccer means there are only so many matches during a year, with only a handful of those possibly in extreme conditions. Furthermore, international friendlies often result in up to six substitutions per match, which further constrains the size of the dataset. We attempted to improve this through utilising >75 min players, an advanced statistical model and investigation of the differences in match-running between full match players and substitutes.
- It is understood that positional movement differences exist in soccer, however, this thesis was not able to analyse this. Whilst, this was possible for match-to-match variation, reporting of clear findings would have been limited in the studies that followed due to the size of the dataset. It should also be noted that team tactics may also play a role in player movement, but due to their complexity in modern football, they were not included for analysis in this thesis.
- Some matches were not included due to errors or missing data. Due to the nature of stadiums, some interfere with GPS satellites, either over- or under-estimating data or not collecting data entirely. Approximately 10 matches were excluded in this thesis, because of these reasons. Unfortunately, this is the nature of data collection with GPS and is unable to be avoided. Therefore, we recommended the use of PlayerLoad as a likely alternative metric for examination of training load.
- The nature of this thesis was retrospective, meaning aspects such as temperature were not recorded manually at all matches. The use of historical data was obtained from a website, with the location of weather stations likely differing from that within the stadium. Collection of temperature using an appropriate thermometer and heat index would provide the best information, particularly immediately prior to kick-off. A large temperature bandwidth was utilised in this thesis, which were unlikely to affect the data processing and classification of temperature.

- The examination of both the congested schedule and altitude, were possibly affected by the small datasets utilised. Although these studies attempted to rectify this through stronger inclusion criteria, it is almost certain that a larger dataset may have provided clearer findings.
- Finally, the examination of preparation for international tournaments provided a novel and detailed look at how an elite female team prepares for these events. This study provided a strong description of how the preparations were designed and implemented. However, this study did not include a performance variable, which meant examination of the effect of a taper was not possible on performance. Inclusion of wellness variables provided a novel look at the perceived effects of a taper and might provide the best indicator of the effectiveness of a taper.

Practical applications

The primary purpose of this thesis was to expand the current knowledge surrounding female soccer, whilst adding to the body of literature examining the effects of match-factors on match-running in soccer. The following practical applications should be considered by practitioners in the field:

- Match-to-match variation should be explored by practitioners with their team. This data will assist with examination of match performances to highlight where a player might be over- or under-performing, or where a match factor is meaningfully affecting performance. This should be accounted for in match-analysis research, using mixed-model statistical designs. These designs analyse changes within players and are most appropriate for these study designs where comparative groups might differ in size.
- The greater occurrence of accelerations warrants the inclusion of such data to better indicate total work/effort and energy consumption. Further, accelerations appear less variable than both high-speed running and sprint-efforts in the examination of match-running performances.
- PlayerLoad also appears less variable between matches than that of high-speed running and sprints. It also appears sensitive to changes in different conditions and

so, therefore, may be a viable alternative to GPS based metrics when GPS satellites are not available, such as in enclosed stadia.

- $Peak_5$ match-running metrics appear similar in variability to that of full match metrics. Practitioners and researchers should look to improve on this method to analyse shorter time periods of a match. The current method appears viable to help inform conditioning protocols utilised by practitioners to prepare players for the worst-case scenario. The design of small-sided games should look to replicate these periods when peak match intensity is intended to be simulated.
- Practitioners should consider match-factors when planning the tactical approach to a match. By deepening the understanding of technical coaches on the physical aspects of a match, the coach may be able to optimise player performance through a match to obtain the best result. Furthermore, knowledge of individual responses to match-factors may provide a coach with the ability to choose a team best suited to a given scenario, such as a match at altitude.
- Where possible, practitioners should report match analyses to both coaches and players with associated match-to-match variation and possible changes in response to present match-factors. This information will enhance both player and coach understanding of performance whilst providing a greater appreciation of changes in match-running.
- The practical scenario of successive matches often results in squad rotation between matches. However, a few players will often be required to play in multiple matches. In these scenarios, individualised recovery and monitoring techniques may be required to make sure these players are always in peak condition for each match.
- The current post-match training techniques used to provide substitutes with a training stimulus leans towards a shorter anaerobic session. However, this may limit their potential when required to complete a full match. A session with greater volume may be required to maintain aerobic fitness levels.
- The use of a simple submaximal running test may provide practitioners with a method of examining the response to altitude. Even where heart rate monitors are available, RPE can provide an indirect measure of internal stress which is possibly more reliable that heart rate measures alone.

- Practitioners should also be aware of the greater contribution of anaerobic energy sources to match-running at altitude. Although match-running may be reduced from sea-level, recovery protocols should be maintained, or adjusted where necessary, to optimise player recovery post-match.
- Monitoring of perceived wellness during a congested schedule or training programme appears important for practitioners to examine the player response to an increase in training load. Whilst, where monitoring of training load is limited, these variables provide a useful way of examining the effects of a taper period through improvements in wellness.

Future research

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

- Where match-factors are being examined, they should be considered in combination rather than isolation. Several factors were identified upon review of the literature, where changes could be likely explained by other factors. This was further reinforced in Chapter four, where the interaction of match outcomes and opposition rankings had varying effects on performance.
- It is known that positional differences exist in match-running. Although this thesis was unable to examine them, considerations should be made to include positional and tactical data in future research. In particular, are these differences greater in different environmental conditions, or in response to different match outcomes or opposition rankings?
- Where examination of temperature is warranted, the use of an appropriate thermometer is suggested. The current thesis was retrospective in nature, therefore, temperature was examined through historical data of the city where each match was played. Although this provides an overview, better information may have been provided through collection of temperature immediately before kick-off.
- Researchers should look to examine the optimal length of a taper, through the inclusion of both wellness and performance indicators. This method will strengthen the approach, by identifying players who may be in a state of overreaching following a period of overloading. Whilst, the supercompensation kinetics of the taper have

been explored, it is unknown if participants were in a state of overreaching which may have affected findings.

- Future research may examine small-sided games constraints in an effort to replicate the intensity of peak match-running metrics. Creating games to replicate the period of the match that exceeds overall match intensity is not well known. Applying these games in a training scenario to monitor the training effect is advised.
- Finally, integration of tactical and technical metrics with physical data appears important to identify the true change in soccer performance in response to different factors. As a sport scientist, we may tend to focus on the physical aspects of sport, however, true soccer performance needs to be considered as a construct. A coach may be more interested in the change in technical or tactical aspects, which in their view, may have a greater impact on match outcome than physical components.

Conclusion

The physical performance of elite female soccer players appears to be affected by numerous factors, often in combination rather than isolation. Practitioners should consider each factor present in combination when analysing match performances. This data can be applied to the training environment, where loads can be forecast to meet the requirements of match-play. Whilst, researchers should look to examine technical, tactical and physical factors in combination, which produce true soccer performance.

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Appendices

Appendix I: Additional research outputs since starting the Doctor of Philosophy.

Publications

Meylan C, **Trewin J**, Mckean K. Quantifying explosive actions in international women's soccer. International Journal of Sport Physiology and Performance. 2017;12(3):310-315.

Conference presentations

Bowman K, Meylan C, Pethick W, Stellingwerf T, **Trewin J**, Koehle M. The efficacy and monitoring of a field-based heat acclimatization protocol to improve performance in elite female soccer players. Sport Innovation Summit. 2015, Toronto, CAN.

Trewin J, Meylan C, Varley MC, Cronin J, Ling D. The effect of match-factors on the running performance of elite female soccer players. Canadian Society for Exercise Physiology Conference. 2016, Victoria, CAN.

Trewin J, Meylan C, Chang-Tsai M, Varley MC, Cronin J. Changes in match-performance and wellbeing during a period of fixture congestion. Sport Innovation Summit. 2016, Calgary, CAN.

Trewin J, Meylan C, Varley MC, Cronin J, Ling D. Match-running in elite female soccer: Match-to-match variation and considerations for match-factors. World Conference on Science and Soccer. 2017, Rennes, FRA.

Bowman K, Meylan C, Pethick W, Stellingwerf T, **Trewin J**, Koehle M. The efficacy and monitoring of a field-based heat acclimatization protocol to improve performance in elite female soccer players. World Conference on Science and Soccer. 2017, Rennes, FRA.

Trewin J, Meylan C, Varley MC, Manson, S, Chang-Tsai M, Cronin J. The reduction in match-running of elite female youth soccer players at 2250 m. Sport Innovation Summit. 2017, Vancouver, CAN.

Appendix II: Ethics approval

University of Victoria | Office of Research Services | Human Research Ethics Board
Administrative Services Building Rm B202 PO Box 1700 STN CSC Victoria BC V8W 2Y2 Canada
T 250-472-4545 | F 250-721-8960 | uvic.ca/research | ethics@uvic.ca

Certificate of Renewed Approval

PRINCIPAL INVESTIGATOR:	**Marc Klimstra**	**ETHICS PROTOCOL NUMBER** Minimal Risk Review - Delegated	**14-037**
UVic STATUS:	**Faculty**	ORIGINAL APPROVAL DATE:	18-Mar-14
UVic DEPARTMENT:	**EPHE**	RENEWED ON:	18-Mar-16
		APPROVAL EXPIRY DATE:	17-Mar-17

PROJECT TITLE: **Longitudinal analysis of physical characteristics, physiological and mechanical loading in international women soccer players**

RESEARCH TEAM MEMBER Data acquisition and analysis: Cesar Meylan (CSA/CSIP), Trent Stellingwerff (CSIP/UVic), Ryan Brodie (UVic), Josh Trewin (CSA); Data Analysis: Kelly McKean (OTP), Ming-Chang Tsai (Univeristy of Toronto) Data analysis: Kelly McKean (OTP)

DECLARED PROJECT FUNDING: **None**

CONDITIONS OF APPROVAL

This Certificate of Approval is valid for the above term provided there is no change in the protocol.

Modifications
To make any changes to the approved research procedures in your study, please submit a "Request for Modification" form. You must receive ethics approval before proceeding with your modified protocol.

Renewals
Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a "Request for Renewal" form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.

Project Closures
When you have completed all data collection activities and will have no further contact with participants, please notify the Human Research Ethics Board by submitting a "Notice of Project Completion" form.

Certification

This certifies that the UVic Human Research Ethics Board has examined this research protocol and concluded that, in all respects, the proposed research meets the appropriate standards of ethics as outlined by the University of Victoria Research Regulations Involving Human Participants.

Rachael Scarth

Dr. Rachael Scarth
Associate Vice-President Research Operations

14-037 Klimstra, Marc

Certificate Issued On: 18-Mar-16

Appendix III: Youth participant consent form

Youth Participant Consent Form

You are invited to participate in a study entitled**: Longitudinal analysis of physical characteristics, physiological and mechanical loading in international women soccer players.** This study is being conducted by Professor Marc Klimstra and Ryan Brodie from the University of Victoria and Dr. César Meylan, the exercise physiologist from the Canadian Sports Institute and Soccer Canada.

Purpose(s) and Objective(s) of the Research:

The use of GPS (Global Position System), Heart Rate (HR) monitoring, accelerometer and physical testing will be used to evaluate the effect of daily training stress (i.e. training load) on the international game activity profile and physical characteristics of players across different age groups (14 y to senior level). The data will provide a greater understanding of the physical demands of elite soccer athletes and be used to prescribe performance support for elite female soccer athletes of different ages and levels. Furthermore, we will evaluate which of these parameters are most effective at prescribing methods getting ready for a major event like the world cup. By tracking changes in an athletes' physical testing, HR monitoring, activity profile on the pitch over an extended period of time, at different levels of physical maturity, we will be able to better determine how training volume and intensity impacts the physical characteristics of elite women's soccer athletes at different ages.

We will use this data to review five purposes and questions:

1) Analysis of GPS/accelerometer/HR data independently and collectively to understand differences in youth and senior game activity profile

2) Does physical testing relate to game performance tracked with GPS and HR?

3) What are the differences in game activity profile and training load between different age groups?

4) Do these parameters vary from game to game, from position-to-position, or with different tactical approaches?

This Research is Important because:

With a better understanding of physical profiling and game activity profiling, coaching can be tailored to the specific needs of a player and position. This could likely have an influence on daily training loads, scheduling, and the final objective of optimizing performance of the National Program. Lastly, information acquired via this research will be valuable for grassroots development of the sport, and could be of interest to a number of parties from the high performance to the research community.

Participation:

You will make no variations in the required schedules developed by the National Women's Soccer program. Due to the multiple year length of this project, your parents and yourself will be asked to provide consent to your participation in the current study on the first camp of the year. Four to five times per year you will be requested to complete a full physical testing battery which are non-invasive in nature. Also, you will put the GPS units and HR monitors on your body using an appropriate strap, 15 minutes prior to any training sessions or friendly competition. Training sessions will take approximately 75 to 120 minutes. Following each session, the data acquired from these units will be exported to a computer and analysed accordingly. These GPS units will be worn for every formal training session and competition involving the National Women's Soccer program.

During physical testing, you will complete the protocols below:

Day 1-

1. Dynamic warm-up
2. 40 meter maximal effort sprint. 1 practice trial, and 2 recorded trials will occur
3. A 1-rep maximal push up test or a maximal number of push ups. You will progressively load and continue to attempt a single push-up until the load of that given movement is not done to completion. Or you will complete as many push ups as possible in rythmn with a metranome.
4. A Jump squat test, administered to develop a a Force-Velocity Profile, will be completed. Squat depth will be self-selected. This value will be recorded for future testing. You will complete 3 countermovement jumps and 3 standing jumps, you may also be asked to complete 3 jump squats with a load of 25,50,75, and 100 pounds each. In such, 12 loaded squat jumps will take place, where jump height measured and maximal force, velocity and power extrapolated.
5. Body mass (in Kg) will be taken along with body composition derived from skinfold test conducted by a certifed female performance nutritionist.

Day 2-

1. The only test conducted on day two will be the 30-15 intermittent test, which is a modified version of the common modified incremental beep test.

Location:

Physical testing will occur at Fortius Health and Fitness Centre in Burnaby, BC. Field selection for training and games will vary according to the predetermined schedule developed by the National Women's Soccer team. There are out-of-province and international matches (friendly) in which the participants will be wearing the GPS and HR monitors, however the use of these technologies are allowed in exhibition matches in accordance to FIFA and international soccer laws.

Benefits:

If you choose to participate in this study, the resulting data may provide insight for improving performance parameters, and information on your activity profiles on field and to the team. No fiscal reward exists.

Withdrawal of Participation:

You may withdraw at any time without explanation or consequence. Should you withdraw, your data will not be used in the analysis and will be destroyed.

Anonymity and Confidentiality:

The gathered results would not be entirely confidential but will only be reported anonymously. To address these issues individuals will not be specifically linked to data and results and individual results will not be shared with others.

The data will be stored on password protected computers only at the Canadian Sport Institute Pacific offices. All paper copies will be stored in a locked filing cabinet in the locked office of one of the co-investigators. The raw data will be stored on a password protected computer only at the Canadian Sport Institute Pacific offices for duration of 5 years. This will allow the researchers to re-analyse the data if necessary.

Research Results will [may] be Used/Disseminated in the Following Ways:

-For research publications, in which all confidentiality will be honored.

-The National Program's staff may use the data's analysis to have a greater understanding of player, positional, and activity profiles, as well as key performance parameters. This could possibly provide further insight for game preparation, game performance and required intervention.

Questions or Concerns:

- **Contact the researcher(s) using the information provided below;**
- **Contact the Human Research Ethics Office, University of Victoria, (250) 472-4545** ethics@uvic.ca
- Contact the researcher using the information provided below:

Researcher:

Marc Klimstra

University of Victoria, Assistant Professor Biomechanics

klimstra@uvic.ca

250 721-8386

Ryan Brodie

Performance Analyst - CSI Pacific

rbrodie@csipacific.ca

250 208 6674

Please fill out this form and bring it to the next **practice or email it to rbrodie@csipacific.ca after having signed it.**

Child's Consent Statement:

I have talked with my parents/guardians about the study: **Longitudinal analysis of physical characteristics, physiological and mechanical loading in international women soccer players,** where I will wear a GPS and HR unit for all required training sessions associated with Soccer Canada. I understand what I will be asked to do. I understand the purpose of the study and my part in it. I understand that I have the option to quit participating in the study at any time without penalty. I also understand that if I quit being part of the study at any time, I can ask that any data that I have provided will be destroyed. My information will be used for research purposes only, and any details that may reveal who I am will not be included in study reports and presentations. If I or my parent/caregiver has any questions, I may call Marc Klimstra at **250-721-8386** or Ryan Brodie at **250-208- 6674**

____________________________ ____________________________

Signature of Child Date

____

Printed name of child

<u>Parent's Consent Statement</u>:

I am the parent/ guardian of ____ and agree to have

(*please print child's first and last name*)

my child participate in the study: **Longitudinal analysis of physical characteristics, physiological and mechanical loading in international women soccer players**. My child is ________ years old and their birthdate is ___________________ (dd/mmm/yyyy).

I understand the purpose of the study and my child's part in it. I understand that they have the option to withdraw from the study at any time without penalty. I also understand that if they withdraw from the study, I can ask that any data that they have provided will be destroyed. Their information will be used for research purposes only, and any details that may reveal who they are will not be included in study reports and presentations. If I have any questions, I may call Marc Klimstra at **250-721-8386** or Ryan Brodie at **250-208- 6674** .

___________________________ ___________________________

Signature of Parent or Guardian Date

____

Printed name of the Parent or Guardian signing above

<u>FUTURE USE OF DATA</u>

As indicated in the study description, our intent is to continue the study over a period of time and to use the information collected from this study to assist future athletes and coaches. We would like to confirm your interest in allowing a future researcher to use your data collected in this study (without personal identification) for future research purposes.

Your signature below indates your consent to allow antoher research to have future access to your data (without personal identification)

Name of Participant	*Signature*	*Date*
Name of Parent/Guardian (if Under 19)	*Signature*	*Date*

If you have any questions or concerns about this study, please do not hesitate to contact Marc Klimstra at klimstra@uvic.ca or Ryan Brodie at rbrodie@csipacific.ca

A copy of this consent will be left with you, and a copy will be taken by the researcher

Approved by the University of Victoria Human Research Ethics Board on 18th of March 2014, HREB reference number: Klimstra 14-037

Appendix IV: Participant consent form

Participant Consent Form

Project Title: Longitudinal analysis of physical characteristics, physiological and mechanical loading in international women soccer players

Purpose(s) and Objective(s) of the Research:

The use of GPS (Global Position System), Heart Rate (HR) monitoring, inertial measurement and physical testing will be used to evaluate the effect of daily training stress (i.e. training load) on the international game activity profile and physical characteristics of players across different age groups (14 y to senior level). The data will provide a greater understanding of the physical demands of elite soccer athletes and be used to prescribe performance support for elite female soccer athletes of different ages and levels. Furthermore, we will evaluate which of these parameters are most effective at prescribing methods of training tapering to prepare for pinnacle events. By tracking changes in an athletes' physical testing, HR monitoring, inertial measurement and time motion analysis of GPS over an extended period of time, at different levels of physical maturity, we will be able to better determine how training load impacts the physical characteristics of elite women's soccer athletes at different ages.

We will use this data to review five purposes and questions:

1) Analysis of GPS/inertial measurement/HR data independently and collectively to understand differences in youth and senior game activity profile

2) Does physical testing correlate with game performance tracked with GPS and HR?

3) What are the differences in game activity profile and training load between different age groups?

4) Do these parameters vary from game to game, from position-to-position, or with different tactical approaches?

This Research is Important because:

With a better understanding of physical profiling and game activity profiling, intervention from coaches, training staff and physiologist can be tailored to the specific needs of a player and position. This could likely have an influence on daily training loads, scheduling, and the final objective of optimizing performance of the 2016 Summer Olympics. Lastly, information acquired via this research will be valuable for grassroots development of the sport, and could be of interest to a number of parties from the high performance to the research community.

Participation:

You will make no variations in the required schedules developed by the National Women's Soccer program. On your first camp of each year, you will be asked to provide your consent to practicipate to this study due to its longitudinal design. Four to five times per year you will be requested to complete a full physical testing battery which are non-invasive in nature. Also, you will secure the GPS units and HR monitors appropriately 15 minutes prior to any training sessions or friendly competition. Training session will take approximately 75 to 120 minutes. Following each session, the data acquired from these units will be exported to a computing system via the manufactured software previously developed, and analysed accordingly. These GPS units will be worn for every formal training session and competition involving the National Women's Soccer program.

During physical testing, you will complete the protocols below:

Day 1-

1. Dynamic warm-up
2. 40 meter maximal effort sprint. 1 practice trial, and 2 recorded trials will occur
3. A 1-rep maximal push up test. You will progressively load and continue to attempt a single push-up until the load of that given movement is not done to completion.
4. A Jump squat test, administered to develop a a Force-Velocity Profile, will be completed. Squat depth will be self-selected. This value will be recorded for future testing. You will complete 3 countermovement jumps and 3 standing jumps, as well as 3 jump squats with a load of 25,50,75, and 100 pounds each. In such, 12 loaded squat jumps will take place, where jump height measured and maximal force, velocity and power extrapolated.
5. Body mass (in Kg) will be taken along with body composition derived from skinfold test conducted by a certifed female performance nutritionist.

Day 2-

1. The only test conducted on day two will be the 30-15 intermittent test, which is a modified version of the common modified incremental beep test.

Location:

Physical testing will occur at Fortius Health and Fitness Centre in Burnaby, BC. Field selection for training and games will vary according to the predetermined schedule developed by the National Women's Soccer team. There are out-of-province and international matches (friendly) in which the participants will be wearing the GPS and HR monitors, however the use of these technologies are allowed in exhibition matches in accordance to FIFA and international soccer laws.

Benefits:

If you choose to participate in this study, the resulting data may provide insight for improving performance parameters, and information on your activity (e.g.running, sprinting, changing direction) profile on field and to the team. No fiscal reward exists.

Withdrawal of Participation:

You may withdraw at any time without explanation or consequence. Should you withdraw, your data will not be used in the analysis and will be destroyed.

Anonymity and Confidentiality:

The gathered results would not be entirely confidential but will only be reported anonymously. To address these issues individuals will not be specifically linked to data and results and individual results will not be shared with others.

The data will be stored on password protected computers only at the Canadian Sport Institute Pacific offices. All paper copies will be stored in a locked filing cabinet in the locked office of one of the co-investigators. The raw data will be stored on a password protected computer only at the Canadian Sport Institute Pacific offices for duration of 5 years. This will allow the researchers to re-analyse the data if necessary.

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- the National Program's staff may use the data's analysis to have a greater understanding of player, positional, and activity profiles, as well as key performance parameters. This could possibly provide further insight for game preparation, game performance and required intervention.

Questions or Concerns:

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- **Contact the Human Research Ethics Office, University of Victoria, (250) 472-4545** ethics@uvic.ca

Researcher(s):

Marc Klimstra	**Ryan Brodie**
University of Victoria	**Performance Analyst - Canadian Sport Institute Pacific**

Assistant Professor Biomechanics

klimstra@uvic.ca

250 721-8386

rbrodie@csipacific.ca

250 588-3948

Consent:

Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

Name of Participant	*Signature*	*Date*

FUTURE USE OF DATA

As indicated in the study description, our intent is to continue the study over a period of time and to use the information collected from this study to assist future athletes and coaches. WE would like to confirm your interest in allowing a future researcher to use your data collected in this study (without personal identification) for future research purposes.

Your signature below indates your consent to allow antoher research to have future access to your data (without personal identification)

Name of Participant	*Signature*	*Date*

A copy of this consent will be left with you, and a copy will be taken by the researcher

Approved by the University of Victoria Human Research Ethics Board on 18th of March 2014, HREB reference number: Klimstra 14-03