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Uncovering the influence of contextual factors on short peak periods in Women's football

Extended introduction, previous literature, methods, and discussion

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Preface

I would like to thank my supervisor Andreas Kjæreng Winther. He has contributed with concrete feedbacks, and I am grateful for our teamwork and instructive conversations regarding my master thesis. Without his help, this master thesis would have been more difficult to complete.

I am also grateful for the opportunity to take part in a bigger and important project like FFRC (Female Research Football Centre). One of my passions in sports, is the fight for more equality in football, and increasing the opportunities for females to develop as football players. FFRC gave me the opportunity to work with a dataset consisting of measurements from top level clubs in Norway, which is both exciting and an important contribution to the research community.

Lastly, I would like to thank my family and closest friends, as they have supported me through these five years of completing my master's degree.

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Introduction

Football provides numerous challenges to strength and conditioning coaches. Mainly, because players must possess multiple fitness components at a high level such as strength, agility, and endurance, whilst having little time to train them (Hennessy & Jeffreys, 2018). In addition, the demands both within and between games can vary considerably, owning to factors such as a players physical capacity, technical skill, position, tactical role and style of play, possession of the team, quality of the opposition, importance of the match, seasonal period, and other environmental factors (Bangsbo, 2014).

Furthermore, it is of huge importance to conduct gender-specific research regarding these demands. Gender differences occur in match performance related to high intensity runs and capacity. Female players experience more muscle fatigue, leading to differences between the genders in the most demanding positions on the field (Bradley et al., 2014). Most research is conducted on males (Kirkendall, 2020). However, the increase of the physical demands in women's football, followed by more resources and growing popularity (*Physical analysis of France 2019 shows increase in speed and intensity* 2020), has impacted the scientific community with focused research regarding the women's game (Mohr et al., 2022). The number of scientific publications has increased, still there exists research gaps related to crucial physical aspects of the women's game.

Research regarding physical demands can allow practitioners to better plan training sessions and individualize programs across positions and players, aiming to improve performance and avoid injuries. Previous research indicates match performance is related to training status (Krustrup et al., 2005), and match demands are higher in matches at a higher level (Andersson et al., 2010; Mohr et al., 2008). Match demands are often derived from either accelerometers and/or GPS, and is popularly described in terms of isolated thresholds such as accelerations (either number of or distance covered), total distance, and distance covered at high speeds (Akenhead & Nassis, 2016). Across tracking systems, the total distance during matches for female footballers is usually in the range of 9.2–11.3 km, while high speed distance covered is around 1.2–2.7 km, and sprint distance 160–460 m (Andersson et al., 2010; Bendiksen et al., 2013; Bradley et al., 2014; Krustrup et al., 2005; Mohr et al., 2008; Vescovi & Favero, 2014).

Moreover, analysis and physiological measurements have revealed that in modern football, the ability to perform repeated high-intensity work are of importance. as e.g., the most successful teams perform more high-intensity activities during a game when in possession of the ball (Iaia et al., 2009). The importance of high-speed running and capability to accelerate, make it interesting to conduct research on these variables' peak periods within a match. Peak periods can increase the quantity of in-game fatigue (Schimpchen et al., 2021), and findings reveal positional differences in the peak 5 min of the game, which further causes a downgrade in physical performance in post 5 min after the peak (Panduro et al., 2022; Winther et al., 2022). Peak periods is both suggested to inform generic training prescription (Delaney et al., 2017), or as benchmarks for exercise replication (Delaney et al., 2015; Oliva-Lozano et al., 2021). Despite this unresolved issue, there is an agreement that average full-match characteristics have limited relevance in athlete preparation. Adaption of such values may not expose players to the most intense periods, which occur intermittently throughout matches (Delaney et al., 2015). Additionally, isolated speed thresholds may have limited value compared to a composed variable. Novak et al. (2021) suggest that a true peak period likely will occur under multivariate conditions, e.g., a high volume of sprinting + acceleration and deceleration (Novak et al., 2021). These statements underline the importance to further investigate peak periods to optimize performance.

Research on full-match characteristics has begun to make its mark in female football, but research on peak periods is still scarce. Harkness-Armstrong et al. (2022) discovered only 8 of 69 studies reported peak match-play characteristics in women's football (Harkness-Armstrong et al., 2022). However, the respective studies only quantified physical characteristics during 5-minute periods. Comparison of the different speed thresholds during peak periods is limited given the different methods adopted, as two studies quantified peak periods by a rolling-average approach, whilst the remaining studies adopted a pre-determined segmental analysis approach (Harkness-Armstrong et al., 2022). Furthermore, only 14 of 69 studies quantified the influence of contextual factors on match-play characteristics, predominantly full-match characteristics. Univariate peak period targets without additional contextual information would likely underprepare players for multivariate scenarios (Novak et al., 2021). Therefore, studies on peak periods may have limited value if additional contextual factors are completely omitted. In fact, a study on male players using a 3 min rolling window, identified that larger peak TD values was associated with earlier occurrence in the match/half, higher uncoupled total out-put, and substitute players. Comparatively, larger peak HSR values was associated with fewer minutes played and higher uncoupled total output, while higher values of peak SP were associated with higher uncoupled total outputs and later occurrence in the half (Novak et al., 2021). Ultimately, the studies quantified contextual factors in isolation, though this most likely is a limitation considered the complex, multifaceted nature of match play-performances (Dalton-Barron et al., 2020). All studies were conducted with a single team, so further research with a multi-club approach, larger sample size and greater number of match observations, is required to identify whether findings are generalizable to the wider women`s football population (Harkness-Armstrong et al., 2022). The reported research gaps give great opportunity to examine peak period as a multivariate construct by including contextual factors, with the thought that these factors have associations with the peak.

Lastly, the nature of the game makes it unavoidable to collect peak data without acknowledging the variability across measurements. This variability has raised questions to its use as benchmark in training sessions (Baptista et al., 2022; Novak et al., 2021). Studies investigated both female and male players, and found that peak 1-min, 3-min and 5-min presents higher variation than full match analysis, regarding high-speed running metrics (Baptista et al., 2022; Novak et al., 2021; Trewin et al., 2018). Suggestions indicates this may be caused by both contextual factors alongside the dynamic and stochastic nature of a football match (Baptista et al., 2022). However, research discovered that peak 1-min presented the lowest variability in nine dependent peak variables when compared to peak 3- and 5-min (González-García et al., 2022). It therefore would be interesting to investigate whether <1-min peak periods, presents even less variation than the existing findings.

Purpose and hypothesis

The presented research gaps regarding peak periods underpins the importance of increasing knowledge on physical demands in women's football. To this date, no other research has studied short peak periods (<1-min). Consequently, the overall aim in the present study is to reach an understanding on how physical and contextual factors correlate in different ways to produce short peak period responses, that potentially could guide the development of robust training programmes. In addition, knowledge on short peak periods can be beneficial for future research to further develop its definition and thereby its use.

Based on a similar study from the men's game (Novak et al., 2021), we hypothesizes that short peak periods are influenced by numerous contextual factors, including position, match half, whether the player is a starter or a substitute, playing home or away and time of occurrence in the match half.

Disposition

This master thesis consists of two parts: this extended version, and a scientific article.

Further in this extended version, a short theory chapter will review the definition and use of the most applicable term in this study; peak period. Then, the previous literature chapter will undergo a narrative review of research conducted on female players regarding peak periods. Relevant results of previous studies will be reviewed in tables and summarised accordingly. Furthermore, the method chapter will deal with subsections; quantitative approach, participants and data collection, variables, validity and reliability of measurement equipment (GPS), ethical considerations, statistical analysis, linear mixed models, and missing data. Finally, a discussion around strength and limitations, ended by practical applications and suggestions to future studies will occur.

The scientific article is separated in chapters following the IMRAD structure. After abstract, introduction; methods; result; and discussion of the result will follow. Conclusion and perspectives will end the article.

Theory

Definition

There are numerous ways to define the highest demanding periods in football and other sports. Terms such as worst-case scenario (Cunningham et al., 2018; Fereday et al., 2020), peak match demands (Whitehead et al., 2018), peak locomotor demands (Weaving et al., 2019), peak movement and collision demands (Johnston et al., 2019) and duration specific running demands (Delaney et al., 2016) has been applied. The present study will refer to this concept by using the term "peak periods".

Method of use

Both method and time length are key variables for influencing the identification of the most intense periods (i.e., peak periods) of competitive match-play. Studies have attempted to assess fluctuations in movement demands during competitive football by dividing matches into discrete "epochs", usually 5-15 min in length (Bradley et al., 2010; Bradley & Noakes, 2013). However, events in football occur randomly, and are thus unlikely to fall within such pre-defined epochs (Fereday et al., 2020). When identifying the peak physical demands, irrespective of time length, a rolling average method is therefore preferable. RA approach offers increased sensitivity and is recommended over pre-defined periods (Fereday et al., 2020; Varley et al., 2012; Whitehead et al., 2018). Hence, the present study will adopt the rolling average analysis method, with time epochs classified as "time periods" <1 min.

Previous literature

Search strategy

A systematic search through the databases Google scholar and PubMed was completed in the start of this process, September 2022. The search strategy included the terms for the population with words like “female” OR “women’s” AND “football” OR “soccer”. “Peak demands” OR “peak periods” AND “match” was then added. Studies were selected through the database search, or in the reference lists of relevant studies. The systematic review by Harkness-Armstrong et al. (2022) was also used extensively.

Studies were included if the relevance to this master thesis occurred, i.e., if the studies contained information about peak periods in women`s football. Therefore, inclusion criteria were female footballers, participants from high level clubs, involvement of peak periods, preferred different playing positions, and competitive match-play. Studies with youth players and training studies were excluded.

Narrative review

Monitoring players through technology devices like GPS is becoming increasingly important in modern, professional football, and is well received by players, coaches, and staff. Previous studies have measured full-match statistics through commonly variables like total distance, high-speed running distance, and sprints (Andersson et al., 2010; Datson et al., 2017; Datson et al., 2014; Milanovic et al., 2017; Mohr et al., 2008; Panduro et al., 2022; Winther et al., 2022). However, it is suggested that average full-match activities have limited relevance in athlete preparation, and that applying such values towards training may not expose players to the most intense periods (Delaney et al., 2015). Therefore, studies aim to imply peak periods within these variables. This chapter will summarize previous research regarding peak periods on female players, with the intention to discover research gaps, but also gain insight on the existing literature on the theme.

Peak periods differ by playing position

Previous studies have investigated peak periods in form of the most intense 5 min- period in elite female football. Panduro et al. (2022) investigated physical performance and loading for six playing positions and discovered positional differences of full-game, end-game, and peak periods. They found that EM, FB and CM performed 25%-34% more HSR than CD, and EM, FW and FB performed 36%-49% more VHSR than CD (Panduro et al., 2022). The study gives important insights on full-game, end-game and peak periods cross positions, as it is a large-scale study covering all eight teams in the Danish women's football league. However, the study lacks insight on less than 5 min peak periods. This leads to the need to lower the minutes of the peak, as this can give expanded knowledge of even more intensive periods of the match.

Physical performance is reduced after peak periods

Winther et al. (2022) also discovered positional differences of physical performance and running intensity fluctuations in elite women's football. Overall, results indicated greater distances were covered during the peak 5-min period than in the next- 5 and mean 5- min periods, and next 5-min periods also presented lower values compared to the mean 5-min of each variable (Winther et al., 2022). This indicates a reduction in physical output after a peak 5-min period in relation to the rest of the match. However, the study lacks information on contextual factors like e.g., match half of peak or match location.

Datson et al. (2017) studied match physical performance of elite female football players during an international competition. The study predominantly studied total match performance, between-half match performance, and the influence of playing position. Regarding peak demands, the study found that the peak THSR distance in a 5-minute period was 223 m +/- 47 m. In the following 5-minute period, the amount of THSR was 39% lower, but was not different to the mean distance covered during all 5-minute intervals, not including the peak distance (Datson et al., 2017). The study provides important values concerning THSR and consist of match observations from over 100 players in different matches, under an international competition. However, concerning peak periods, the study is scarce. With only THSR distance as variable, in a peak 5-min period, the need for a wider scope regarding peak periods is needed in future research.

Peak periods vary from match-to-match

There exist match-to-match variation of the match running in female elite football. Trewin et al. (2018) results indicate that high-speed running per minute exhibited the greatest variation in the post-peak 5-min period. Peak periods were also observed as slightly more variable than full-match analyses (Trewin et al., 2018). This may indicate that contextual factors have an influence on peak/post-peak periods. The study suggests the use of 5-min time periods to identify peak periods, though one must acknowledge how unstable HSR and sprint monitoring is due to its variation. The study has further limitations when its research was on a single-team and can doubtfully be generalized to other teams. It also implies few matches as the data spreads over 5 years, i.e., the players physical performance can change and improve during that period. This increases the importance of this thesis to contain several teams, over a shorter period with more games, so the results can be generalized and more valid.

Collecting data on peak values from match-to-match, provides an understanding on the fact that values vary, and it is important to acknowledge the sources of variability when investigating peak periods. Baptista et al. (2022) studied the variability of physical match demands in elite women's football. With exception to sprint distance, all other metrics presented a higher observed match-to-match variability in the 1-min peaks than in the full match. Different sources of variability seem to impact differently the match physical performance of players (Baptista et al., 2022). In general, this shows practitioners that we must recognize that the phenomenon varies from match-to-match, and that using specific benchmarks in this area should be avoided. This challenges future studies to discover less variable match measurements, to substantiate the argument of using peak periods in practice. Still, this does not affect the importance of gaining knowledge about the most intense periods, in advance to training planning with interest to optimize performance of our players and be prepared for the most demanding load.

Contextual variables influence peak periods

González-Garcia et al. (2022) is at this point the only study that investigate whether contextual variables play a role on peak physical demands, on elite female football players. They aimed to describe and compare the peak physical demands through the worst-case scenario method, according to different rolling average time epochs (1, 3 and 5 min) and contextual variables. With a width of including nine peak-dependent variables and four independent contextual variables (position, match half, location and match outcome), the results showed differences between positions, but only TD, acceleration and deceleration peak-dependent variables were affected by match half and match outcome. 1-min RA time epochs exhibited the lowest variability, which allows greater accuracy and reliability to identify nine key peak period outcomes in elite women football (González-García et al., 2022). However, the study only applied one team and they did not research <1-min peak periods. This master thesis will investigate peak 10/30/60 seconds, with a multi-club approach.

Peak periods differ by gender

Bradley et al. (2014) studied gender differences in match performance characteristics of football players competing in the UEFA Champions league. Regarding peak demands, the distance covered during the most intense 5 min period of the match at a speed threshold >15 km, was higher in male compared to female players. Differences were also evident between gender for the next and average 5 min period during the match. Although, male and female players did not illustrate a distance deficit in the next versus the average 5 min period (Bradley et al., 2014). Like previous literature, this study just illustrates peak 5 min of one isolated variable, HSR distance. Yet, it shows the importance of conducting gender-specific research, which also arise the issue of determining relative speed thresholds for male and female players.

Level and competitive setting affect peak periods

Andersson et al. (2010) results indicated that elite female football players perform more high intensity running when playing international games compared with domestic league games. They investigated both HIR and sprints. The peak 5-min HIR was 151 ± 7 m in INT games and 134 ± 6 m in DOM games. In the following 5-minute period, the amount of HIR was 79 ± 11 and 67 ± 8 m, respectively. Furthermore, the HIR in the peak distance in INT (151 ± 7 m) was 52% higher, than the average distance covered during all 5-minute intervals, not including the peak distance (73 ± 35 m). In DOM, the peak distance was 53% higher (134 ± 6 m) than the average distance covered during all 5-minute intervals not including the peak distance (63 ± 31 m) (Andersson et al., 2010). This indicates that contextual factors like match frame influences the players external load, though the complex nature of a football game always consists of several influencing factors.

In closing, Mohr et al. (2008) looked at match activities of elite women football players at different performance levels. Peak distance covered by high intensity running in a 5-minute interval was 33% longer for the top-class players (183 ± 9 m) than the high-level players (138 ± 8 m). In the following 5 minutes immediately after the peak interval, top-class players covered 17% less (77 ± 6 m) high intensity running than the game average (93 ± 5 m). The relatively large difference in high intensity running between the two levels clearly shows the importance of being able to perform high intense running bouts repeatedly and to recover from these actions throughout the game (Mohr et al., 2008). The study gives important insight in how performance level reveal differences in players capability to perform high speed running, which was the intent of the study. This indicates the need of quantifying match characteristics, as well as peak demands, in isolation of the different performance levels. However, the combination of a small sample size, only one variable (HSR), and only peak 5 min, leaves huge research gaps regarding peak periods in female football.

Overview of studies

All studies (excluding Baptista et al. 2022 which lacks peak characteristics) is listed in Table 1 and Table 2, regarding peak (5,3 and 1 min) physical characteristics of women's football match-play:

TABLE 1. PEAK PHYSICAL CHARACTERISTICS FOR 5 MIN IN WOMEN`S FOOTBALL MATCH-PLAY

Study	Group	Velocity ($km \cdot h^{-1}$) or ($m \cdot s^{-1}$)/ Acceleration ($m \cdot s^{-2}$) thresholds	Method	Position	TD Peak 5 min	HSR Peak 5 min	VHSR Peak 5 min	SPR Peak 5 min	ACC Peak 5 min	DEC Peak 5 min
Panduro et al. (2022)	DOM D1	HSR:>15 VHSR:>18 SPR:>25 ACC:>3 DEC:<-3	Fixed time periods	CD FB CM EM FWD	625 ±27 664 ± 47 683 ± 57 658 ± 52 639 ± 74	132 ± 36 169 ± 37 165 ± 42 177 ±37 167 ± 32	74±20 101±28 91±27 110±24 104±28	12±9 21±14 19±14 29±20 24±18	2.4±1.2 2.3±1.0 2.3±1.1 1.9±1.6 2.6±1.4	2.7±0.8 3.2±0.9 3.3±1.0 3.7±1.0 3.6±1.0
Winther et al. (2022)	DOM D1	HSRD: > 4,44 $m \cdot s^{-1}$ SPD: >5,55 $m \cdot s^{-1}$ Nr of acc/dec (>/< 2,26 $m \cdot s^{-2}$) Peak speed	Rolling average approach	CB FB CM WM FW	634±21 688±22 706±20 712±26 658±31	139±13 190±13 179±12 210±14 164±16		54±6 82±6 63±6 92±7 67±8	56±4 66±4 56±3 74±4 62±5	41±3 50±3 45±3 59±3 46±4

González-Garcia et al. (2022)	DOM D1	HSR: >15 VHSR: >18 SPR: >21 Acc/dec: >2m · s^{-2}	Rolling average approach	All	123,85 m/min	15,67 m/min	8,61 m/min	4,63 m/min	11,03 m/min	1,36 m/min
Trewin et al. (2018)	INT	HSR:>16.48 ACC:>2.26	Rolling average approach	All CB FB MID FWD	704±59 658±49 718±46 732±50 707±61	123±41 101±45 153±39 126±34 127±31			17±3 17±3 18±3 15±3 17±4	
Datson et al. (2017)	INT	HSR: >14,4	Fixed time periods	All		223±47				
Bradley et al. (2014)	DOM D1	HSR:>15	Fixed time periods	All		149±6				
Andersson et al. (2010)	INT vs DOM D1	HSR: >15 SPR: >25	Fixed time periods	All All		151±7 vs 134±6		43±3 35±3		

Mohr et al. (2008)	Top class/high level	HSR: >15	Fixed time periods	All All		183±9/ 138±8				

TABLE 2. PEAK PHYSICAL CHARACTERISTICS FOR 1- AND 3 MIN IN WOMEN`S FOOTBALL MATCH-PLAY

Study	Group	Velocity ($km{\cdot}h^{-1}$) or ($m{\cdot}\ s^{-1}$) /acceleration ($m{\cdot}\ s^{-2}$) thresholds	Method	Position	TD	HSR	VHSR	SPR	ACC	DEC
Winther et al. (2022) **Peak 1 min**	DOM D1	HSRD: > 4,44 $m{\cdot}s^{-1}$ SPD: >5,55 $m{\cdot}s^{-1}$ Nr of acc/dec (>/< 2,26 $m{\cdot}\ s^{-2}$) Peak speed	Rolling average approach	CB FB CM WM FW	174 ± 15 192± 16 189 ± 14 191 ± 19 178 ± 23	71 ± 9 93 ± 9 85 ± 9 93 ± 11 77 ± 12		37 ± 4 53 ± 4 40 ± 4 54 ± 5 44 ± 6	28 ± 2 32 ± 3 28 ± 2 34 ± 3 31 ± 3	20 ± 2 24 ± 2 21 ± 2 27 ± 2 23 ± 3
González- Garcia et al. (2022) **Peak 1 min**	DOM D1	HSR: >15 VHSR: >18 SPR: >21 Acc/dec: >2m$\cdot\ s^{-2}$	Rolling average approach	All	167,80 m/min	47,12 m/min	30,54 m/min	19,06 m/min	31,55 m/min	3,65 m/min
González-Garcia et al. (2022) **Peak 3 min**	DOM D1	HSR: >15 VHSR: >18 SPR: >21 Acc/dec: >2m$\cdot\ s^{-2}$	Rolling average approach	All	133,39 m/min	21,43 m/min	12,50 m/min	7,12 m/min	15,03 m/min	1,80 m/min

Summary of peak physical characteristics in women's football match-play

The literature search found nine studies quantifying the peak physical characteristics of women's football match-play, on elite/high level players (Andersson et al., 2010; Baptista et al., 2022; Bradley et al., 2014; Datson et al., 2017; González-García et al., 2022; Mohr et al., 2008; Panduro et al., 2022; Trewin et al., 2018; Winther et al., 2022). The reported peak data are presented Table 1 and Table 2. Six of these studies quantified only peak 5 min (Andersson et al., 2010; Bradley et al., 2014; Datson et al., 2017; Mohr et al., 2008; Panduro et al., 2022; Trewin et al., 2018), while Baptista et al. (2022) studied 1 min peak variability, Winther et al. (2022) studied 1- and 5 min peak, and González-Garcia et al. (2022) studied peak 1,3- and 5-min. Five studies adopted a pre-determined segmental analysis approach (Andersson et al., 2010; Bradley et al., 2014; Datson et al., 2017; Mohr et al., 2008; Panduro et al., 2022), while the remaining four adopted a rolling average analysis approach (Baptista et al., 2022; González-García et al., 2022; Trewin et al., 2018; Winther et al., 2022).

The use of different number of -and different speed thresholds varies, whereas the newer studies cover a wider scope of different speed thresholds and represent more varied use of methods. This reflects a development in the research community concerning player tracking on female players. Other remarks show weaknesses are to be find in every study regarding the generalization to the wider female football population. The studies consist of small sample sizes, either with few observations, only one team, only one league/competition, or a large spread of the data which can affect the results outcome.

Methods

Research project and purpose

This master thesis is conducted in cooperation with the research project Female Football Research Centre (FFRC), directed by UiT – The Arctic University of Norway. The project's main purpose is to collect and gain new and fundamental insight and knowledge on performance factors that affect performance development and health for female elite players. The data collection consists of physiological measurements from match and training (work package 3 – physiology), which further increases our knowledge of the players' external load and running patterns on a professional level.

Quantitative approach

The issue of this master thesis will be answered by collecting and analysing quantitative data through GPS measurements, which will increase our knowledge on match physical peak demands for female players and uncover whether contextual factors influence. This gives implications to further optimization and development of performance. Through a deductive approach, theories and hypothesis will be verified or falsified at the end of the analysis of the statistics (Nyeng, 2012, pp. 59-60). After processing the numbers from GPS through statistical analysis, the goal of the present study is to generalize to a larger population, in this case Norwegian elite female football players.

Participants and data collection

Four teams from the top division in Norway were observed through two seasons (2020-2021), resulting in 3123 total observations (distribution shown in Table 3). The players wore GPS tracking equipment (STATSports Apex, Northern Ireland) in matches. Inclusion criteria was that the players competed at the highest level in Norway (Toppserien). For each player, each match, TD, HSD, SD and HEL (SD + acceleration distance + deceleration distance) was investigated as peak 10, 30- and 60 sec, and was calculated using a rolling average analysis approach. This technique can be applied to numerous external load variables (e.g., distance, average speed, high speed running, average acceleration, metabolic power and collisions) and across numerous durations (e.g., 10 sec -10 min), as used in previous studies on male players (Cunningham et al., 2018; Delaney et al., 2016; Delaney et al., 2015; Delaney et al., 2017; Weaving et al., 2019).

Contextual variables were collected, including player position, match half, if the player was a starter or substitute, match location (home/away) and time in half in which the peak period occurred. Only outfield players were included in the study. Right back and left back were classified as wide defender, right winger and left winger were classified as wide midfielder, and defensive and offensive midfielder were classified as central midfielder. Right and left centre back were classified as central defender, and strikers were classified as striker.

TABLE 3. OVERVIEW OF OBSERVATIONS

Half	Position	Total number of observations	Number of players	Mean number of observations per player	Minimum	Maximum
First	CD	310	24	12.9	1	39
First	CM	568	50	11.4	1	37
First	S	170	27	6.3	1	17
First	WD	233	30	7.8	1	34
First	WM	151	33	4.6	1	27
Second	CD	314	26	12.1	1	38
Second	CM	699	62	11.3	1	38
Second	S	231	42	5.5	1	18
Second	WD	260	43	6.0	1	34
Second	WM	187	41	4.6	1	28

Variables

TABLE 4. VARIABLE DESCRIPTIONS

	Variable	Type	Units
Dependent	Total distance (TD)	Continuous	Complete load, Meters (m)
	High-speed distance (HSD)	Continuous	>4.44 m.s-^{1}
	Sprint distance (SD)	Continuous	>5.55 m.s-^{1}
	High external load (sprint+acc+dec) (HEL)	Continuous	>5.55 m.s-^{1} + the distance covered with a positive or negative change in speed of more than ±2.26 m.s−2, with a minimal effort duration of 0.3 s, finishing when the rate of acceleration/deceleration reached 0 m.s−2 (Winther et al., 2022)
Fixed	Position	Nominal	Central defender (CD), Wide defender (WD), Central midfielder (CM), Wide midfielder (WM), Striker (S)
	Match half	Nominal	First half, second half
	Starter vs. sub	Nominal	Starter and sub
	Home/away	Nominal	Home and away
	Time in half	Continuous	Minutes
Random	Player ID	Nominal	Unique ID
	Match ID	Nominal	Unique ID

Validity and reliability of GPS tracking equipment

From a methodological perspective, instruments should be evaluated based on their validity and reliability.Validity is concerned with whether the measuring instrument measures the behaviour or quality that is intended to measure, and is a measure of how well the instrument performs its function (Anastasi & Urbina, 1997). Reliability is an indicator of the stability of the measured values obtained in repeated measurements under the same circumstances using the same measuring instrument (Sürücü & Maslakçi, 2020). The data in this study was collected using GPS tracking equipment (STATSports Apex, Northern Ireland). GNSS (global navigation satellite system) is the most wearable athlete monitoring system for outdoor use, as it provides meaningful position-based measures such as speed or path length for team sports (Luteberget & Gilgien, 2020). However, one must be aware that GNSS is prone to measurement error, and the factors that can influence position validity. E.g., under certain circumstances, other tracking systems like Local Position Measurement (LPM) have better accuracy than GPS-based systems (Pettersen et al., 2018). Consequently, validity needs to be investigated prior to use, often through reference systems applied to validate such wearable athlete monitoring systems and the parameters investigated (Luteberget & Gilgien, 2020).

GPS is practical and simple in use for the players, and do not follow with disturbing factors or strain. Previous studies have tested if the equipment is valid and reliable in measuring distance and top speed (Beato et al., 2018; Beato & de Keijzer, 2019; Scott et al., 2016). Scott et. al (2016) collected all studies that have evaluated either or both the validity and reliability to GPS units in team sport, with focus on distance measurements, speed thresholds and acceleration. The results showed that all GPS units, independent of sampling rate, is capable of tracking players in these categories within team sport, with sufficient reliability. 10 Hz units is per date the most valid and reliable regarding linear/team sport stimulated running (Scott et al., 2016), and is the applied version in this study.

Ethical considerations

All participants have been informed and have given written consent, and thus can withdraw from the study at any time. Personal identifiers were removed from the data files when used for statistical analyses. All FFRC protocols have been submitted to approval to the Norwegian Social Science Data Services and Regional Committees for Medical and Health Research Ethics (REK), and NSD- Norwegian Centre for research data.

Statistical analysis

Linear mixed models

All statistical analysis in this thesis were conducted using R 4.0.2. Data included clustered, non-independent, and repeated measures of match observations (players clustered within matches, and uneven number of observations per player). Hence, a statistical procedure known as linear mixed modelling (LMM) approach was applied. LMM are an extension of simple linear models and is a method for analysing data that are non-independent, multilevel/hierarchical, longitudinal, or correlated (UCLA, 2021).

LMM allow both fixed and random effects and thereby dissect the data by separating the variance due to random sampling from the main effects. Generally, one should consider all factors that qualify as sampling from a population as random effects (players/matches in repeated measurements), and everything else as fixed (contextual factors) (Lima, 2017). The present study estimated the association between four dependent variables (TD, HSD, SD and HEL) and five independent variables (position, match half, starter vs. sub, home/away and time in half). The significance level was set at 0.05.

Missing data

In a study with many observations and big sample size, one must be prepared to deal with missing data in the dataset. Missing data is defined as the data value that is not stored for a variable in the observation of interest. First, the absence of data reduces statistical power. Second, the lost data can cause bias in the estimation of parameters. Third, it can reduce the representativeness of the samples. Lastly, it may complicate the analysis of the study. Each of these, may threaten the validity of the results and further lead to invalid conclusions (Kang, 2013).

In general, there are three types of missing data. The first is missing completely at random (MCAR). This occur when the probability that the data are missing is not related to either the specific value which is supposed to be obtained or the set of observed responses. I.e., if data are missing by design, because of an equipment failure or because the samples are lost in transit or technically unsatisfactory. The statistical advantage of data that are MCAR is that the analysis remains unbiased (Kang, 2013). The second type of missing data is missing at random (MAR). Data are MAR when the propensity for a data point to be missing is not related to the missing data but is related to some of the observed data, i.e., the missingness is conditional on another variable (Grace-Martin). The last type is the category of missing not at random (MNAR). The cases of MNAR data are problematic. The only way to obtain an unbiased estimate of the parameters in such a case is to model the missing data (Kang, 2013).

Missing data in our dataset

The missing data in the present study is likely a combination of both missing completely at random (MCAR) and missing at random (MAR). For instance, some missing data could simply be due to a coach forgetting to turn on some of the GPS pods at the appropriate time. Some matches were also played in an indoor arena, which is an example of MAR. Here the missingness can be attributed to a known factor (an indoor arena).

As there are different types of missing data, there are several ways to deal with them. For the purpose of this thesis, it was decided that complete case analysis (CCA) was an appropriate approach. Here, only rows that are not missing (e.g., complete) are included (Little et al., 2022). CCA is the default method in much statistical software and is practical in this case as it does not require any additional coding. However, the main drawback is a loss of observations and hence statistical power (Little et al., 2022).

Model interpretation

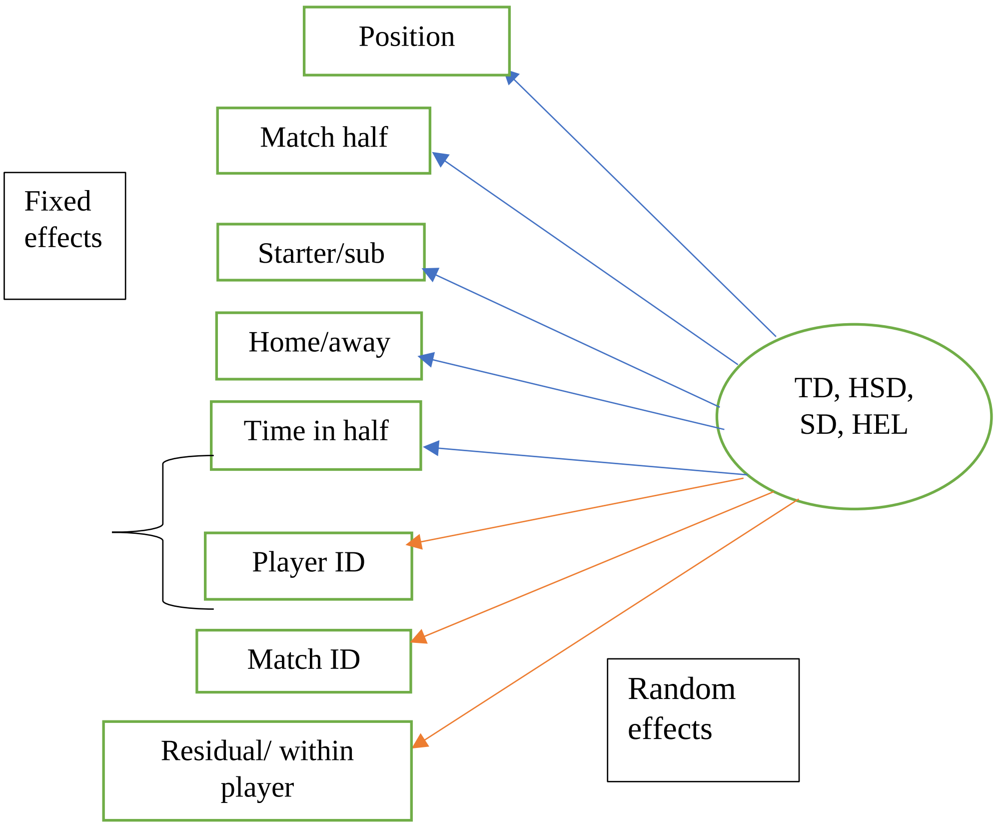

FIGURE 1. FIXED EFFECTS ARE HYPOTHESIZED TO HAVE ASSOCIATIONS WITH THE FOUR DEPENDENT VARIABLES, TOTAL DISTANCE, HIGH SPEED DISTANCE, SPRINT DISTANCE AND HIGH EXTERNAL LOAD. RANDOM EFFECTS INDICATE SOURCES OF VARIANCE ATTRIBUTED TO REPEATED MEASURES OBTAINED FROM THE SAMPLE.

This section details how to read a linear mixed regression model. Fixed effects are here simply referred to as the effects of interests (Gelman, 2005). In this case, we want to know how variables affect the short peak periods. Random effects are sources of variability we want to account for (Gelman, 2005), namely repeated measures of matches and repeated observations of different players. Fixed effect coefficients are typically read as “a one unit increase in the independent variable is associated with an increase of “x-amount” in the dependent variable”. On the other hand, random effects are expressed either as a variance or standard deviations and indicate by how much the short peak periods vary across players and matches. The residual indicates how much variability is left unexplained in the model. In repeated measure designs, the residual captures the variability in the response variable that is unique to each subject and is not explained by the fixed or random effects. Hence, it is sometimes referred to as the “within-subject” variability or “within-player” variability in this case.

Positional group was a nominal fixed effect. Here central defender was coded as 0, and hence the effect of all other positional groups is relative to the mean of the central defenders. We calculated coefficient estimates and 95% confidence intervals (CI) for each independent variable in each peak period model.

The effect of match half is the change in physical output for a peak period performed in the second half, relative to first half. The starter vs. substitute presents values performed by the substitute, compared to a starter. Likewise, the home/away variable presents values from when a player is playing away, compared to playing home.

Lastly, since time in half is a continuous variable, it notes how a one unit increase in time, increases, or decrease the physical output during a peak period. I.e., an indication on how the time of occurrence in the half affects the peak period, for a player playing from the first minute. If the statistical analysis displays an increase of e.g., 0.1202, this means that with a reference value of e.g., 38 m, the formula will be 38 m + 1 min • 0.1201. Meaning statistically, it will increase with 0.1201 m per minute of the half. However, this most likely will not occur as a linear outcome in practice.

Strengths and limitations

One of the present study biggest strengths is the sample size. Compared to other studies conducted on female players, we collect observational data on several teams over a great period, which is rare and novel in studies on female elite players. By doing this, we can with more confident generalize to the wider population of female footballers playing the highest division in Norway. However, the number of observations was slightly unevenly distributed between the four teams, so overgeneralizing should be done with care.

Recommended by previous research, we also created a composed variable (sprint+ acc & dec) closer to a more precise definition of peak period, as isolated speed thresholds most likely do not reflect peak period well enough (Novak et al., 2021). Nevertheless, the study first and foremost illustrates if contextual factors influence <1-min peak periods TD, HSD, SD and HEL, which no previous research have investigated before. We now have reference values on short peak periods (10, -30- and 60 seconds) performed by different playing positions, which allows coaches to plan training drills more easily, with aim to achieve the same values in training. Finally, we account for the reasons for variability in our measurements, which consider the dynamic and stochastic nature of the game.

However, the present study consists of limitations, which further leads to challenges of use. First, contextual factors were investigated in isolation, which might underestimate the full picture, considered the complex, multifaceted nature of match play-performances (Dalton-Barron et al., 2020). The only study of our knowledge that investigated match factors together, is Trewin et al. (2018), as they e.g., found that match outcome had an interactive effect with opposition rankings in the examination of match running (Trewin et al., 2018).

Secondly, as previous studies arise question marks to the use of peak periods in practice (Novak et al., 2021), it concurrently sets limitation to the use of the present study`s results. When peak period is analysed as univariate metrics, it follows poor consistency (e.g., HSD and SD), and it is suggested that training prescription should avoid using specific benchmarks to achieve, but rather promote the presence of varied training stimulus and intensities (Baptista et al., 2022). The concept of peak periods has not been well defined, and the applicability to training and physiological adaptions as a result of training with peak periods, requires further investigation (Novak et al., 2021).

Thirdly, the present study lacks any internal load responses. This is considered an important research gap, as a combination of external and internal load would reflect a more complete picture of the highest physical demanding periods. The resulted values are position specific, and by using general thresholds that applies for all individual players, we must acknowledge the fact that the values do not reflect a true physiological relevance for each individual player (Novak et al., 2021).

Practical applications and future studies

Practical applications

As the transfer of longer peak periods (e.g., 5 min) to training can be difficult for practitioners due to the complexity of the content, short peak periods <1-min can be easier to apply. Based on our results, coaches can e.g., plan position-specific sprinting drills at the end of a training session, in a range of 28-36 m, as this was the mean performed sprinting range for positions in the three time periods. WD might need to be exposed to greater amount of sprint in training, as it was the only position statistically significant from the intercept in SD and HEL. The reasons for WD being the most demanding position, could be related to shorter time periods than other studies, or may be related to the four teams' formation/style of play (Riboli et al., 2021). WD is the position that have experienced the most increase on high intensity running distance and sprints, because of the evolving tactics in modern football over the last years (Bush et al., 2015).

Still, there exists challenges of this suggested use. We must acknowledge the fact that such values correspond to just a proportion of the total activity and load that the players have been exposed for in the actual moments of the measurement. The use of an "average" positional or even individual peak may prepare the players for an average demand, computationally cutting 50% of the peak (Novak et al., 2021). Hence, since peak period data derive from matches, the aim should be to manipulate the intensity of such values in the position-specific-, possession-, SSGs-, tactical- and technical-based training modes (sport-specific activities), as these training modes often account for 90 % of the total training drill prescription (Barrett et al., 2020). Consequently, it is suggested that peak periods are inappropriate to prescribe the intensity of running based activities such as intervals, repeated sprint and linear speed training modes (Weaving et al., 2022), as the structure of these training modalities is vastly different. Therefore, short peak periods should not be intended as universal benchmarks for every training mode (Weaving et al., 2022), but rather help to understand relevant physical characteristics to train (Novak et al., 2021).

Future studies

The data indicates that short peak physical characteristics are position-dependent, thus practitioners should implement position-specific practices to prepare players accordingly for the varying short peak periods in match-play (Harkness-Armstrong et al., 2022). Therefore, training studies concerning short peak periods is needed to develop confidence around whether it is a trustable variable for practitioners to use when planning training sessions. The study investigate the influence of match-related contextual variables in matches, making it interesting for future investigations to analyse the effect that match-related contextual variables have on the weekly training load, but also on the peak periods from training session (Rago et al., 2021).

As the present study only identify for acceleration and deceleration in the composed variable HEL, identification of accelerations and decelerations count on short peak periods to know the peak external neuromuscular load of elite women's football matches (González-García et al., 2022) would be of interest. Likewise, analysis on any internal load variable on <1-min peak periods is needed, as previous studies only investigated e.g., heart rate on peak 5 min (Panduro et al., 2022).

In closing, future research should quantify the associated technical and tactical characteristics during short peak periods, to understand how technical-tactical roles may influence. It would also be of interest to investigate how other contextual factors (e.g., match status, formation, opposition quality, ball possession) together influence short peak periods. Consequently, researchers and practitioners should remain cognisant of the strengths and limitations of all measurements used to evaluate different training modalities across the complexity of the overall training programme (Weaving et al., 2022).

As football is complex and the peak demands are affected by several factors, it is a complicated task for both researchers and practitioners to account for every factor that affect peak periods, and how peak periods further affects performance. Yet, it is of importance to keep conducting research concerning these intense periods, to create an understanding on how physical and contextual factors combine in different ways to produce peak period responses, as this further guide the development of robust training programs and better prepared players.

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Uncovering the influence of contextual factors on short peak periods in Women's football

Article

Carine Brekkan Kristensen

Master's thesis in Sports Sciences. IDR-3901. May 2023

Table of Contents

Table list

Abstract

Aim: The purpose of the present study was to investigate whether different contextual factors influence short peak periods, and further uncover its reasons for variability, in female football matches. Different rolling average (RA) time periods (10, 30 and 60 seconds) was applied. **Methods**: With an observational study design, 59 players from four elite women's football teams in Norway`s top division were monitored during competitive matches over two seasons, with 3123 match observations. Total distance (TD), high-speed distance (HSD), sprint distance (SD), and high external load (HEL) were established and assessed. 5 independent contextual variables were assessed including position (CD, WD, CM, WM, and S), match half, starter vs. substitute, home/away, and time in half. Physical performance data was collected using STATSport GPS APEX. Linear mixed modelling was used to account for cross-sectional observations and repeated measures. **Results**: Position showed statistical significance as a contextual factor on several occasions, particularly WD presented higher values than all other positions. Playing first-half and away matches were more demanding than playing second-half and at home. Whether a player is a starter or a substitute, varied across different metrics. Lastly, the time of occurrence in half affects the outcome of short peak periods. **Conclusions:** As this is the first study conducted on short peak periods <1-min in female football, using TD, HSD, SD and a composed variable HEL, practitioners more easily can develop training drills that better reflect peak periods. Coaches and players must take in consideration the multivariate combination of physical and contextual factors that affect short peak periods in training planning and acknowledge the variability of measuring peak periods through distance metrics.

Key words: global positioning system, physical demands, short peak periods, women's football

Introduction

Football provides one of the greatest challenges to strength and conditioning coaches with the many components needed to perform at a high level (Hennessy & Jeffreys, 2018). Several factors have an impact on players' physical demands during match-play. Factors like physical capacity, technical skills, position, tactical role and style of play, possession of the team, the quality of the opposition, importance of the match, seasonal period, and other environmental factors (Bangsbo, 2014). The physical demands of women's football have increased in recent years. Yet, systematic training models and programs are necessary to improve the physical status of female players to further increase the level and intensity of the game (*Physical analysis of France 2019 shows increase in speed and intensity* 2020). Even though women's football has surpassed a transformation as a result of increased professionalism, research on female players is still minimal, and most of it are related to injury (Kirkendall, 2020). Hence, studies on match physical performance and demands are highly needed and should be a priority in the football research community.

Monitoring of physical demands and high intensity runs

There has been an increased focus to practitioners on the overall monitoring of player workloads, in an attempt to understand the stress placed on the player during training and match play, with the goal of maximizing performance (Gabbett, 2010; Watson et al., 2017). The main objectives of player tracking are 1) better understanding of practice (provide an objective, a posteriori evaluation of external load and locomotor demands of any given session or match), 2) the optimization of training load patterns at the team level and 3) decision making on individual players training programs to improve performance and prevent injuries (Buchheit & Simpson, 2017).

Four of the top-five ranked variables used to monitor training load derive from microtechnology incorporating Global Positioning Systems (GPS), variables like acceleration (various thresholds), total distance, and distance covered above 5,5 m/s (Akenhead & Nassis, 2016). Previous studies on female footballers shows that across tracking systems, the total distance during matches, usually is in the range of 9.2–11.3 km, while in high speed distance it is covered around 1.2–2.7 km, and sprint distance 160–460 m (Andersson et al., 2010; Bendiksen et al., 2013; Bradley et al., 2014; Krustrup et al., 2005; Mohr et al., 2008; Vescovi

& Favero, 2014). Modern football is highly energetically demanding (Iaia et al., 2009), and physical match performance varies in close relation to differences in players physical capacity. This underlines the importance of strengthening both external and internal capacity, so the ability to perform a bigger amount of high intensity runs and sprints increase (Andrzejewski et al., 2013; Krustrup et al., 2005).

Peak periods and contextual factors

Full-match characteristics from specific speed thresholds might underestimate players for the peak demands. This may lead to suboptimal preparation of athletes to cope with the most intensive periods of the game (Delaney et al., 2015; Gabbett et al., 2016). Studies concerning peak periods discovered e.g. positional differences in the peak 5 min of the game, and how peak variables can be affected by contextual factors (González-García et al., 2022; Panduro et al., 2022; Winther et al., 2022). Studies on male players have observed how position, match half, location (home or away) and match outcome increases or decreases the peak during matches (Oliva-Lozano et al., 2020). However, investigation of peak (e.g., 1, 3 and 5 min) presents higher variation than full match analysis (Baptista et al., 2022; Novak et al., 2021; Trewin et al., 2018), with peak 1-min being the least variable in comparison to 3- and 5-min peaks (González-García et al., 2022). Match-to-match variation is unavoidable in football, and may be caused by both contextual factors alongside the dynamic and stochastic nature of a football match (Baptista et al., 2022).

Moreover, different methods have been developed aiming to identify peak periods. Some studies have examined pre-defined epochs (Bradley et al., 2014; Datson et al., 2017; Panduro et al., 2022), while others used the later recommended rolling average approach (RAA) (Baptista et al., 2022; Trewin et al., 2018; Winther et al., 2022), as it demonstrated higher sensitivity to identify peak periods (González-García et al., 2022). A final remark suggest that the use of normally speed thresholds (TD, HSD etc.) might not reflect the peak periods well enough, as it is a multivariate construct, consisting of high volume of sprinting, acceleration + deceleration and other implements (Novak et al., 2021).

All this considered, the aim of the present study was to investigate whether different contextual factors (position, match half, starter vs sub, home/away and time in half) have an influence on short peak periods (<1-min) in competitive female football matches. No other studies have investigated shorter peak periods than 1-min. Secondly, we aimed to identify the distribution of the sources of variability in these intense periods. This could potentially guide the development of robust training programmes and be beneficial for future research to further develop peak period`s definition and thereby its use.

Methods

Study design, subjects, and procedure

Following ethical institutional approval from the Norwegian Centre of Research Data (reference number: 296155) and written informed consent from the participants (59 players, 22 ± 4 years of age), four top-level clubs from Norway were included and observed in the study (3123 match observations). The data was collected from official matches over two seasons (2020-2021), using GPS APEX (STATSposrts), with a sampling frequency of 10 Hz. The validity and reliability of this tracking system has been accounted for in previous studies (Beato et al., 2018; Beato & de Keijzer, 2019; Scott et al., 2016). In every match, each player wore a tight vest with the GPS unit on the back of their upper body between scapula, as described by the manufacturer. To minimize inter-devices error (Beato et al., 2018), each player used the same GPS unit during the entire season (Winther et al., 2022).

TABLE 1. OVERVIEW OF OBSERVATIONS

Half	Position	Total number of observations	Number of players	Mean number of observations per player	Minimum	Maximum
First	CD	310	24	12.9	1	39
First	CM	568	50	11.4	1	37
First	S	170	27	6.3	1	17
First	WD	233	30	7.8	1	34
First	WM	151	33	4.6	1	27
Second	CD	314	26	12.1	1	38
Second	CM	699	62	11.3	1	38
Second	S	231	42	5.5	1	18
Second	WD	260	43	6.0	1	34
Second	WM	187	41	4.6	1	28

Physical performance variables

Speed thresholds were chosen according to previous research (Strauss et al., 2019; Trewin et al., 2018), and the variables were used to analyse short peak periods of 10/30/60 seconds. The time periods should be as short as possible as the primary aim of this study is to determine the highest peak values (Weaving et al., 2022).

TABLE 2. VARIABLE DESCRIPTIONS

	Variable	Type	Units
Dependent	Total distance (TD)	Continuous	Complete load, Meters (m)
	High-speed distance (HSD)	Continuous	>4.44 $m.s^{-1}$
	Sprint distance (SD)	Continuous	>5.55 $m.s^{-1}$
	High external load (sprint+acc+dec) (HEL)	Continuous	>5.55 $m.s^{-1}$ + the distance covered with a positive or negative change in speed of more than ±2.26 $m.s^{-2}$, with a minimal effort duration of 0.3 s, finishing when the rate of acceleration/deceleration reached 0 $m.s^{-2}$ (Winther et al., 2022)
Fixed	Position	Nominal	Central defender (CD), Wide defender (WD), Central midfielder (CM), Wide midfielder (WM), Striker (S)
	Match half	Nominal	First half, second half
	Starter vs. sub	Nominal	Starter and sub
	Home/away	Nominal	Home and away
	Time in half	Continuous	Minutes
Random	Player ID	Nominal	Unique ID
	Match ID	Nominal	Unique ID

Statistical analysis

The short peak periods were statistically analysed in R 4.0.2, using linear mixed model approach. Random effects were specified to account for the clustered nature of player and match observations, as well as the repeated measures for individual players across matches. The player ID and match ID were modelled as crossed effects, as all players did not compete in all matches. All independent variables were included in all models.

Positional group was a nominal fixed effect, and interpretations of positional group was relative to the reference value of central defenders (CD). The variable of match half was coded as 0 = first half, and 1 = second half, while starter /sub was coded as 0 = starter and 1 = sub. Home/away was coded as 0 = home and 1 = away. Time in half is a continuous variable indicating the effect of the time at which the peak occurs has on the distance covered. Significance level was set at 0.05.

Each player, each match, within each period (10, 30- and 60 seconds) of TD, HSD, SD and HEL, was calculated using the recommended rolling average analysis approach (Fereday et al., 2020; Whitehead et al., 2018). Right back and left back were classified as wide defender, right winger and left winger were classified as wide midfielder, defensive and offensive midfielder were classified as central midfielder, and right and left centre back were classified as central defender. Strikers were classified as striker. Goalkeepers were not included.

Handling of missing data

Studies of training load and injury risk should report how missing data are handled (Bache-Mathiesen et al., 2022). It is assumed that the missing data in the present study is MCAR (missing completely at random), or MAR (missing at random). The missing data in our dataset are either missing by design (equipment failure or samples lost in transit, MCAR), or the missingness can be attributed to a known factor (an indoor arena, MAR). Thus, in our case CCA (complete case analysis) was applied. Previous studies have showed that multiple imputation is not necessary before mixed-model analysis of longitudinal data (Twisk et al., 2013).

Results

Mean peak values and variability per positional group are presented in Table 3, included mean peak values of match half (second half), starter vs. sub (sub), home/away (away), and time in half. The reasons for variation in the sample are presented in Table 4, including all metrics.

TABLE 3. MEAN PEAK VALUES PER POSITIONAL GROUP AND OTHER CONTEXTUAL FACTORS

	Meters	**Std. Error**	**P value**
TD 10 sec			
(Intercept)	49	0.69	< 0.01
Central Midfielder	0.7	0.65	0.28
Striker	0.5	0.74	0.47
Wide Defender	2	0.66	**0.00**
Wide Midfielder	0.4	0.75	0.58
Match half	-0.6	0.25	**0.01**
Starter vs. sub	-0.8	0.44	0.055
Home/away	0.7	0.36	0.06
Time in half	0.08	0.009	**<0.01**
TD 30 sec			
(Intercept)	103.2	1.36	<0.01
Central Midfielder	3.0	1.25	**0.01**
Striker	0.5	1.42	0.67
Wide Defender	5.4	1.26	**<0.01**
Wide Midfielder	2.0	1.45	0.16
Match half	-2.8	0.45	**<0.01**
Starter vs. sub	2.4	0.82	**0.00**
Home/away	0.8	0.75	0.27
Time in half	0.12	0.01	**<0.01**
TD 60 sec			
(Intercept)	169.3	2.07	< 0.01
Central Midfielder	6.2	1.91	**0.00**
Striker	2.7	2.17	0.21
Wide Defender	8.3	1.91	**<0.01**
Wide Midfielder	4.8	2.20	**0.02**
Match half	-6.1	0.68	**< 0.01**
Starter vs. sub	5.3	1.23	**<0.01**
Home/away	0.8	1.13	0.44
Time in half	0.11	0.02	**<0.01**
HSD 10 sec			

(Intercept)	42.4	0.97	<0.01
Central Midfielder	1.7	0.92	0.056
Striker	1.4	1.05	0.15
Wide Defender	3.7	0.94	**<0.01**
Wide Midfielder	2.0	1.06	0.06
Match half	-0.6	0.34	0.07
Starter vs. sub	-1.8	0.62	**0.00**
Home/away	0.9	0.50	0.051
Time in half	0.12	0.01	**< 0.01**
HSD 30 sec			
(Intercept)	53.7	1.67	< 0.01
Central Midfielder	3.8	1.53	**0.01**
Striker	1.6	1.74	0.33
Wide Defender	7.2	1.54	**<0.01**
Wide Midfielder	3.6	1.77	**0.04**
Match half	-1.9	0.55	**0.00**
Starter vs. sub	1.2	0.99	0.21
Home/away	1.8	0.87	**0.03**
Time in half	0.13	0.02	**<0.01**
HSD 60 sec			
(Intercept)	64.1	2.00	< 0.01
Central Midfielder	6.3	1.79	**0.00**
Striker	3.2	2.02	0.10
Wide Defender	10.4	1.76	**<0.01**
Wide Midfielder	5.1	2.04	**0.01**
Match half	-3.9	0.61	**<0.01**
Starter vs. sub	4.2	1.12	**0.00**
Home/away	2.3	0.98	**0.01**
Time in half	0.13	0.02	**<0.01**
SD 10 sec			
(Intercept)	28.2	1.21	< 0.01
Central Midfielder	0.2	1.14	0.83
Striker	-0.1	1.29	0.88
Wide Defender	2.7	1.14	**0.01**
Wide Midfielder	0.3	1.31	0.77
Match half	-0.8	0.41	0.052
Starter vs. sub	-2.1	0.74	**0.00**
Home/away	1.3	0.58	**0.02**
Time in half	0.10	0.01	**<0.01**
SD 30 sec			
(Intercept)	29.7	1.36	<0.01

Central Midfielder	0.3	1.26	0.81
Striker	-0.1	1.43	0.91
Wide Defender	3.5	1.26	**0.00**
Wide Midfielder	0.2	1.44	0.86
Match half	-1.0	0.45	**0.01**
Starter vs. sub	-1.1	0.81	0.14
Home/ away	1.4	0.62	**0.02**
Time in half	0.10	0.01	**<0.01**
SD 60 sec			
(Intercept)	31.5	1.52	< 0.01
Central Midfielder	1.0	1.39	0.44
Striker	0.2	1.58	0.86
Wide Defender	4.7	1.38	**0.00**
Wide Midfielder	1.2	1.59	0.43
Match half	-1.7	0.48	**0.00**
Starter vs. sub	-0.4	0.88	0.64
Home/away	1.7	0.68	**0.01**
Time in half	0.10	0.01	**<0.01**
HEL 10 sec			
(Intercept)	45.1	1.47	< 0.01
Central Midfielder	-2.3	1.36	0.08
Striker	-1.5	1.54	0.32
Wide Defender	2.1	1.35	0.11
Wide Midfielder	-1.4	1.55	0.34
Match half	-2.1	0.47	**<0.01**
Sub vs. starter	-1.0	0.87	0.24
Home/away	1.8	0.66	**0.00**
Time in half	0.13	0.01	**<0.01**
HEL 30 sec			
(Intercept)	52.4	1.79	< 0.01
Central Midfielder	-1.4	1.64	0.36
Striker	-0.6	1.85	0.71
Wide Defender	3.8	1.61	**0.01**
Wide Midfielder	-1.1	1.86	0.54
Match half	-3.0	0.56	**<0.01**
Sub vs. starter	1.3	1.03	0.20
Home/away	2.2	0.74	**0.00**
Time in half	0.11	0.02	**<0.01**
HEL 60 sec			
(Intercept)	60.2	2.12	< 0.01
Central Midfielder	0.4	1.89	0.82

Striker	2.3	2.13	0.26
Wide Defender	6.0	1.84	**0.00**
Wide Midfielder	1.2	2.14	0.57
Match half	-4.8	0.64	**<0.01**
Starter vs. sub	3.4	1.17	**0.00**
Home/away	2.3	0.80	**0.00**
Time in half	0.13	0.02	**<0.01**

Total distance

Positional differences occurred in the 30- and 60 seconds (sec) TD peaks. CM and WD were significantly different from the intercept (CD) in the 30 sec peak, presenting higher TD peak values than CD. In the 60 sec peak, CM, WD and WM showed statistical significance, also presenting higher values of TD peak than CD. The CD performed 49 m, 103 m and 169 m of TD peak respectively. The mean peak total distance performed by all positions in all time periods, was in a range from 49-178 m performed.

Statistical significance occurred on match half in all time periods, indicating players perform lower values of TD peak in the second half. Substitutes tended to produce higher TD peak values than starters, as the starter vs sub variable showed statistical significance in the 30- and 60 sec peaks. The home/away variable showed no significant differences in all time periods, i.e., playing home or away does not affect the TD peak values. Statistical significance occurred in all time periods in the time in half variable, i.e., the time of occurrence in the half affects the outcome of TD peak.

High speed distance

Statistical significance from the intercept (CD) occurred on WD (10 sec), CM, WD and WM (30 sec), and on CM, WD and WM (60 sec), meaning the effect of positional group was strong. HSD mean peak values for CD (intercept) was 42 m, 54 m, and 64 m respectively. The mean peak HSD performed by all positions in all time periods, was in a range from 42-74 m. WD presented the highest values in all time periods (4 m, 7 m, and 10 m respectively longer than the intercept), also being the only position significantly different from the intercept in HSD 10 sec.

Match half showed statistical significance on HSD 30 sec and 60 sec, indicating that a player performs lower HSD values in second half than in the first half. The effect of starter vs substitute occurred in 10- and 60 sec, indicating that a substitute performs lower HSD values in the 10 sec., but higher values in the 60 sec. Additionally, statistical significance occurred in home/away 30-and 60 sec, indicating a player performs longer HSD values when playing away. Statistical significance occurred in all time periods in the time in half variable, i.e., the time of occurrence in the half effects the outcome of HSD peak.

Sprint distance

Significant differences in SD only occurred on WD from the intercept (CD), in all time periods. WD performed around 3-5 m longer SD than all other positions. CD performed 29 m, 30 m, and 32 m respectively, and the mean peak SD performed by all positions in all time periods, was in a range of 28 m- 36 m.

Match half showed statistical significance in the 30- and 60 sec peaks, i.e., players perform lower SD peak values when playing in the second half. For the starter vs. substitute variable, statistical significance only occurred in the 10 second peak, i.e., substitutes perform lower SD peak values than starters. Further on, statistical significance occurred in all time periods in the home/away variable, meaning players performs longer SD peak values when playing away. Statistical significance occurred in the time in half variable in all time periods, i.e., the time of occurrence in the half effects the outcome of SD peak.

High external load

The effect of different positional group was not strong on HEL, except WD presenting statistical significance in the 30- and 60 sec time periods, with 4-6 m longer performed HEL than the intercept (CD). CD performed 45 m, 52 m, and 60 m respectively. The mean peak HEL distance performed by all positions in all time periods, was in a range from 43-66 m performed.

Match half was statistically significant and showed lower HEL values for the second half in all time periods. Statistical significance occurred in the starter vs substitute variable only in the 60 second time period. I.e., a substitute performs higher values of HEL 60 second than a starter. Home/away was statistically significant in all time periods, meaning players perform longer HEL values when playing away. Statistical significance occurred in all time periods in the time in half variable, i.e., the time of occurrence in the half effects the outcome of HEL peak.

Variability

TABLE 4. VARIABILITY OF PEAK 10/30/60 SECONDS LOCOMOTOR DEMANDS EXPRESSED IN SD (STANDARD DEVIATION)

Metric	Peak	Between match	Between player	Within player
TD (m)	10 sec	1.7	2.8	6.5
	30 sec	3.9	6.1	12.1
	60 sec	5.7	9.8	18.2
HSD (m)	10 sec	2.4	4.1	9.2
	30 sec	4.3	7.7	14.7
	60 sec	4.9	10.4	16.4
SpD (m)	10 sec	2.6	5.7	10.9
	30 sec	2.8	6.7	11.9
	60 sec	3.1	7.9	12.9
HEL (m)	10 sec	3.0	7.5	12.7
	30 sec	3.1	9.7	15.0
	60 sec	3.2	12.2	17.0

Table 4 shows that the reason for variation is mostly due to the variability of each individual player (within player), a lower amount is due to the variation between the players (between player), and the least amount is due to the variation that occurs from match to match (between match). All random effects show lower variation as time period decrease. In "within player", TD 10 sec shows the lowest variation. However, all other three metrics, especially SD and HEL show the least variation inside the respective metrics, with SD being the least variable from time period to time period.

Discussion

To our knowledge, this is the first study that 1) investigated <1-min (10 sec, 30 sec and 60 seconds) short peak physical demands, 2) used a composed variable (high external load), 3) have a multi-club approach resulting in a large dataset, concerning short peak demands and contextual factors, and 4) uncovered the reasons for variation on short peak periods, overall on female elite players.

Position

Several findings arise from this study. The impact of positional group as a contextual factor was relatively strong and occurred in all four thresholds, though the differences between positions appear as minor in practice. In TD, the performed meters were in a range of 49 m-178 m, all time periods and positions included. For HSD, performed meters were from 42 m-75 m, for SD 28 m-36 m, and for HEL 43 m-66 m. In both TD and HSD, several positions (WD, CM an WM) showed statistical significance from the intercept (CD) and presented higher values in the 30- and 60 second time periods. WD presented the highest mean peak values in all thresholds and was the only position that showed statistical significance from the intercept in SD, HEL (30 sec/60 sec), and HSD (10 sec).

Differences concerning positions occurred when comparing with previous research. WD being the definitive highest demanding position regarding high intensity thresholds, is not the case in other studies, using >1-min time periods. Studies found that CM covered the greatest TD, and WM covered the greatest HSR, VHSR and SPR distances (Harkness-Armstrong et al., 2021; Panduro et al., 2022; Winther et al., 2022). Some discovered that WM and F presented higher values in peak 1-min for VHSR, while for SP the highest peak 1-min were observed for WM, WD and F (González-García et al., 2022; Winther et al., 2022).

Furthermore, Panduro et al. (2022) concluded that only CD stands out in the 5 min peak period. CD performed lower distance in sprinting than EM, lower VHSR than FB, EM and FW, and lower HSR distance than FB, CM and EM (Panduro et al., 2022). In similar, Winther et al. (2022) concluded that CD is the least physical demanding position in high intensity runs >1 min. Even though our study reflects similar trends regarding differences between positions in TD, HSD and SD, the composed variable HEL contradicts the statement of CD being the least demanding position. Only WD showed statistical significance from CD in HEL, and CD even presented higher values of HEL than other positions (though the values did not reach statistical significance). This indicates that CD get expose to the same, and higher demands than other positions when acc and dec is included in the metric. >1-min time periods with isolated speed thresholds, might then not reflect the highest demanding periods well enough. This can lead to an underestimation of CD`s physical demands compared to other positions, which might underprepare CD for their peak demands. Direct comparison between the studies must take into consideration that Panduro et al. (2022) applied another tracking system and used pre-defined 5-minute periods (Fereday et al., 2020; Varley et al., 2012). Overall, we can predict that the differences between the present study and other studies is a consequence of different time periods (<1-min vs. >1-min), which highlights the importance of conducting this research.

Match half, starter vs. sub, home/away and time in half

Studies suggest that peak periods are position specific, as it is mainly position as contextual factor that influence 1/3- and 5-min periods (González-García et al., 2022). However, in the present study, all the other contextual factors influence the 60,30- and 10 sec time periods.

Lower values of TD, HSD, SD and HEL occurred in the second half compared to the first half, in almost every time period (HSD/SD 10 sec only exception). This may indicate that match tempo decreases in the second half, which agrees with the fact that female players experience more muscle fatigue as the match goes on (Bradley et al., 2014). A previous study investigated peak speed between match half's and found lower number of VHSR for all positions in the second half (except FB). Decreases of acceleration and deceleration also occur in the second half for different positions (Panduro et al., 2022). However, González-Garcia et al. (2022) showed no statistical significance on match half in any high intensity variable (HSR, VHSR and SPD).

The impact of whether the player is a starter or a substitute, varied in the different thresholds and time periods. In TD, a substitute presented higher values in peak 30-and 60 sec. A substitute presented lower values in HSD 10 sec, but higher values in HSD 60 sec. In SD, a substitute presented lower values in 10 sec, and higher values in HEL 60 sec. The variation makes it difficult to determine general assumptions. However, the values indicates that substitutes perform higher values as time periods increase. Novak et al. (2021) found similar results on male players. Substitutes tended to produce higher values of peak TD, and a lower number of minutes played was associated with higher values of peak HSR (Novak et al., 2021).

The home/away variable showed no statistical significance in TD, but in all time periods of the remaining three thresholds (HSD, SD, HEL), i.e., players perform higher values of short peak periods when playing away. This indicates that away matches are more demanding regarding high intensity runs and sprints. Again, this does not reflect the results of González-Garcia et al. (2022), as they found no significant interaction between match location and peak values (González-García et al., 2022).

Interestingly, our study shows a minor increase on the variable time in half on all metrics, meaning larger peak TD/HSD/SD/HEL values were associated with later occurrence in the half. For every minute of 45 min, the peak value will statistically increase with values in-between 0.10091 - 0.13982 m. Even though statistically time in half affect the outcome of the peak, it will most likely not have a linear impact from the 1.-45 min in practice. The results contradict with similar studies conducted on male players, where they discovered only peak SD to be associated with later occurrence in the half/match (Novak et al., 2021).

The differences in findings between the present study and other studies, is again most likely due to the different time periods and tracking systems used. Higher peak demands occur in shorter time periods, as the peak distance is more evenly spread (Winther et al., 2022).

Speed thresholds and time periods

As we now have reference values for short peak periods <1-min concerning 5 positional groups, coaches can more easily plan training drills to reach these levels of demands. For instance, González-Garcia et al. (2022) uses 9 dependent variables on >1-min time periods. Rarely will one of these measurements isolated reflect the real peak, making it difficult for coaches to know the best use of it in practice. The present study is the first that include a composed variable, consisting of sprint+ acc and dec in the same metric. The majority of high-speed running and sprinting bouts occur over distances of less than 10 m (Datson et al., 2017; Mara et al., 2017), which highlights the importance of accelerations and decelerations (Griffin et al., 2020). The metabolic cost is also higher for accelerations and decelerations compared to running at a constant velocity (Osgnach et al., 2010). Peak is thereby better considered as a composite construct which may be induced by various combinations of physical activity and contextual factors (Novak et al., 2021).

We found it most beneficial to study short peak periods <1-min, as 1-min RA identifies the peak with the highest accuracy and lower variability in several studies (Doncaster et al., 2020; González-García et al., 2022; Harkness-Armstrong et al., 2021; Weaving et al., 2022). This indicates that <1-min peak periods more likely consist of the toughest external load through the entire duration and presents even less variation in-between positions. Time periods of 3-5-min might underestimate TD by 25,8% and 35,5% respectively, while for HSR, VHSR and SP distances, by 119-167 % and 201-312 % (González-García et al., 2022).

Variability

One of our aims was to identify the reasons for variation in each metric. On the surface it seems that most of the variability in distance covered in any metric is found in the residual (within player), which practitioners and researchers is recommended to account for when examining match performances (Trewin et al., 2018). The high-speed metrics (SD and HEL especially) present less variability within the metric, compared to TD, but no remarkable differences occur between TD and high-speed metrics. On the other hand, the results reflect the poor consistency of specific peak high-speed metrics, which agrees with other studies on both female-and male players (Baptista et al., 2022; Novak et al., 2021). Peak periods analysis may help to understand relevant physical characteristics to train, but we must raise questions to its practical applicability as benchmarks for training sessions (Novak et al., 2021). For instance, peak speed as metric shows far less variation from match-to-match than distance-metrics (Baptista et al., 2022), and no positional differences on peak speed in both full-game and peak 5 min. Peak speed did also not differ between halves (Panduro et al., 2022). Therefore, the use of peak speed could potentially be a more credible metric to use as benchmark for practitioners in the daily training planning.

In final, the present study consists of some shortcomings. We only accounted for a subset of the peak periods metrics that exists, and even though we accounted for acceleration and deceleration in the HEL variable, the present study provides limited knowledge on acc and dec in short peak periods. Additionally, the study only accounted for five categorized positions, and observations per positions were unevenly distributed which could have affected the outcome. Future studies should aim to account for all eleven positions on the field within different formations, with aim to expand our knowledge on short peak periods.

Conclusion

The present study revealed that contextual factors do influence <1-min short peak periods in women's football. As the study gathered mean peak values of five categorized positions in four different speed thresholds, the overall conclusion is that WD is the most demanding position in <1-min peak periods, with CD sometimes being equally demanding to other positions as the intensity of the peak increases and involve acceleration and deceleration. The first half is more physically demanding than the second half, same as playing away matches is more demanding than playing home, in high-intensity thresholds. Whether a player is a starter, or a substitute varied too much to draw any general assumptions. Time of the occurrence in the half influenced the players performed distances.

Perspectives

The results of the present study emphasize the relevance of monitoring physical match demands with a specific focus on short peak periods <1-min, as shorter time periods more likely reflect a higher peak and presents less variation. The highly physically demands placed on all outfield positions, highlight the importance of specific position preparation, with intention to cope with the occurring match demands. Coaches must know the impact of other contextual factors as well in terms of load management of the players. However, further investigation is needed concerning the peak periods challenges of use. Combination of training studies and match analysis, and external and internal load, is needed to know whether training adaptions to short peak periods have positive impact on players load and experience of the most demanding periods in match.

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