Wik, E. H., Luteberget, L. S., Spencer, M. (2016). Activity profiles in International female team handball using PlayerLoad™. *International Journal of Sports Physiology and Performance*, under utgivelse. doi: 10.1123/ijspp.2015-0732

Note. This article will be published in a forthcoming issue of the *International Journal of Sports Physiology and Performance*. The article appears here in its accepted, peer-reviewed form, as it was provided by the submitting author. It has not been copyedited, proofread, or formatted by the publisher.

Section: Original Investigation

Article Title: Activity Profiles in International Female Team Handball Using PlayerLoad™

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Journal: *International Journal of Sports Physiology and Performance*

Acceptance Date: November 7, 2016

DOI: http://dx.doi.org/10.1123/ijspp.2015-0732

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Original Investigation

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Preferred running head: Activity profiles in team handball

Abstract word count: 248

Text only word count: 3528

Number of figures and tables: 5 figures + 2 tables

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Abstract

Team handball matches place diverse physical demands on players, which may result in fatigue and decreased activity levels. However, previous speed-based methods of quantifying player activity may not be sensitive for capturing short-lasting team handball-specific movements. ***Purpose:*** To examine activity profiles of a female team handball team and individual player profiles, using inertial measurement units (IMUs). ***Methods:*** Match data was obtained from one female national team in nine international matches (n=85 individual player samples), using the Catapult OptimEye S5. PlayerLoad™·min^{-1} was used as a measure of intensity in 5- and 10-minute periods. Team profiles were presented as relative to the player's match means, and individual profiles were presented as relative to the mean of the 5-minute periods with >60% field time. ***Results:*** A high initial intensity was observed for team profiles, and for players with ≥2 consecutive periods of play. Substantial declines in PlayerLoad™·min^{-1} were observed throughout matches for the team, and for players with several consecutive periods of field time. These trends were found for all positional categories. Intensity increased substantially in the final five minutes of the first half for team profiles. Activity levels were substantially lower in the five minutes after a player's most intense period, and were partly restored in the subsequent 5-minute period. ***Discussion:*** Possible explanations for the observed declines in activity profiles for the team and individual players include fatiguing players, situational factors and pacing. However, underlying mechanisms were not accounted for, and these assumptions are therefore based on previous team-sport studies.

Keywords: training load, accelerometer, IMU, team sports, fatigue

Introduction

Knowledge of physical demands of team handball is required in order to identify talents and develop position-specific training programs for individual athletes[1]. Research on team handball is relatively limited, and methodologically challenging compared to other team sports, such as soccer, rugby, and Australian football[1-3], due to technological limitations in monitoring indoor sports and capturing short high-intensity actions performed in tight spaces. Furthermore, the literature is male dominated, and since game dynamics and player demands differ between the genders[4], analyses of player activity on males may not be accurate for females.

Female players were in one study found to cover 2.5% of total distance in high-intensity running categories[5], which suggests high-intensity activity accounts for a relatively small part of the physical aspect of the game. On the other hand, these are often performed in tight spaces on a small court[1], which restricts high absolute velocities, and therefore the quantity of high-intensity activity when using locomotor categories. Consequently, previous speed-based methods may not have been sensitive enough to detect efforts demanding maximal or near maximal effort from the athlete. In addition, differences in definitions of high-intensity activity complicate the interpretation further.

The introduction of inertial measurement units (IMUs) with accelerometers, gyroscopes, and magnetometers has allowed for more detailed quantification of both high-intensity, sport-specific actions, and external load. PlayerLoad™ has been developed as a measure of physical performance based on changes in acceleration, with the aim of capturing non-running based work (e.g. jumping, changes of direction, and tackles)[6], which would not be captured as precisely using traditional time-motion analysis. The use of devices for physical activity profiling is already common practice, also during competition, in team sports such as Australian Football, field hockey, rugby, and soccer.

A consistent finding in time-motion studies of team handball is overall decreases in high-intensity activity in the second half[2,3,5,7]. Additionally, studies have reported declines in physical performance after team handball match play[7-9]. Declined activity relative to playing time from the first to the second half is also reported in other team sports[10-13]. Furthermore, activity levels have been reported to be below the match average five minutes after the most intense period of soccer games, with values restored to baseline values ten minutes after this period[14,15]. Decreased activity in the five minutes following a peak period is also reported by a similar study of rugby league[16]. These results support the occurrence of "transient" fatigue in team sports, however, this has not been investigated in team handball. To the authors' knowledge, there are currently no studies using IMUs and PlayerLoad™, or related measurements of workload, in team handball games.

Based on shortcomings in the available literature on team handball, in regard to activity profiling and indications of fatigue during matches, the purpose of this study was to examine activity profiles of international female team handball matches, using IMUs. Specifically, fatigue development, indicated by temporal or transient changes in physical activity, was of interest, both on a team and individual player level. Based on previous studies we expected to find variations in activity levels, with decreased intensity within and between halves.

Methods

Subjects and design

The current study was observational, where the Catapult OptimEye S5 (Catapult Sports, Australia) was used to obtain match data from female national team players, competing in nine international team handball matches. These were played in the 2014/2015 Golden League tournament series, which consisted of three sub-tournaments in which the team played three matches in four days (Figure 1). Goalkeepers were excluded from all analyses. This resulted in a sample of 18 individual outfield subjects included in the analyses. The analyzed players were each represented 1-9 times (mean ± SD; 4.7 ± 2.8), resulting in a total of 85 match data samples (Table 1). Players participated voluntarily, and data storage was approved by the Norwegian Social Science Data Service.

Methodology

PlayerLoad™ relative to playing time was used as a measure of intensity, to account for between-player differences in field time. PlayerLoad™ is an accelerometer-derived measurement of external physical loading, which calculates instantaneous rate of change in acceleration for the X, Y, and Z axis, sampling at 100 Hz[6]. The equation for calculating PlayerLoad™ is described below:

$$PlayerLoad^{\text{™}} = \sqrt{\frac{(a_{y1} - a_{y-1})^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2}{100}}$$

a_y = *forward acceleration*
a_x = *sideways acceleration*
a_z = *vertical acceleration*

Acceptable within- and between-device reliability of Catapult Sports IMUs have been reported in laboratory and field tests (MinimaxX 2.0; CV = 0.91-1.94%)[17], along with moderate to high test-retest reliability of PlayerLoad™ and the individual vectors contributing to it in a treadmill test (MinimaxX; CV = 5.3-14.8%, ICC = 0.80-0.93)[18]. Unpublished reliability data from our laboratory has demonstrated a CV for PlayerLoad™·min^{-1} of 0.9% (90% confidence limits (CL) = 0.8-1.0%) in team handball training sessions using the OptimEye S5.

Athletes were familiarized with data collection procedures in training sessions prior to games. The unit was located between the shoulder blades in a custom-made vest (Catapult Sports, Australia), which was fitted under the match jersey prior to the pre-match warm up. During matches, signals were tracked via telemetry using specialized software (Catapult Sprint, version 5.1.4, Catapult Sports, 2014). Interchanges were made continuously, ensuring that only time spent on the field was included in the analyses. During time-outs, all players were inactivated. The interchange area was video-recorded to ensure that uncertainties and eventual errors could be double-checked and corrected after the game.

Match data were downloaded from the IMUs to Catapult Sprint using a USB-interface, and were exported to Microsoft® Excel® (Microsoft Corporation, USA). 5-minute periods were calculated from the start of each half, and only full 5-minute periods were included in the analyses. Due to stoppages during play, the duration of halves varied within and between games and could be longer than the effective half time of 30 minutes. 10-minute periods covered the absolute first and final ten minutes of each half, in addition to the middle ten minutes, originating in the exact middle point of the half.

Only players completing a minimum of 60% of a given period were included in the individual analyses of fatigue, while all players with a minimum of one minute on the field in a given period were included in the analyses of team activity. In the team analyses, players in each period were compared against their match mean, and values in each period represent a percentage of this baseline value. In the individual analyses, baseline 5-minute mean values were calculated from the 5-minute periods in the game satisfying the 60% inclusion criteria.

In the analysis of individual temporal fatigue, consecutive 5-minute periods fulfilling the inclusion criteria for field time were analyzed for each half. A player's first 5-minute period with 60% field time was considered their first period of play in the respective half, independent of game time. Subsequent periods fulfilling the criteria were then counted as their second, third, fourth etc. consecutive period of play. Consecutive periods could not cross the half-time break, and only bouts of a minimum of two consecutive periods were included. In this manner, each player could be represented twice in a game, with one bout in the first- and one in the second half. In the analysis of transient fatigue, each player's peak 5-minute period was identified for each match. The peak period was then compared to the preceding 5-minute period (Pre) and subsequent 5-minute (Post-5) and 10-minute (Post-10) period, given that these periods also fulfilled the criteria of 60% of playing time.

Statistical analysis

Results are presented as mean ±90% CL. Differences between periods of the match were calculated by using a customized spreadsheet[19] in Microsoft® Excel® (version 12.3.6, 2008). Magnitude based inferences were used to describe probabilities of single or pooled periods being substantially higher, trivial, or lower than the comparison. Qualitative inferences were made, based on the probabilities, with the categories; most unlikely (<0.5%), very unlikely (0.5-5%), unlikely (5-25%), possibly (25-75%), likely (75-95%), very likely (95-99.5%), most likely (>99.5%). Threshold chances of 5% for substantial magnitudes were used, meaning a likelihood with >5% in both positive and negative directions was considered an unclear difference[20].

Results

The match mean of PlayerLoad™·min^{-1} and mean field time per game for outfield positions combined, and positional categories are presented in Table 1. Scoring details, including mean goals scored and conceded in each half are presented in Table 2.

Team activity profiles

Values of PlayerLoad™·min^{-1} for the 10-minute periods are presented in Figure 2A and 2B. For outfield players combined, and all positional categories, the first ten minutes were substantially higher than the following periods in the first half and the first period of the second half. For outfield players combined and pivots, the final ten minutes of the second half were substantially lower than the middle ten minutes of the second half and the last period of the first half. For backs, the final ten minutes of the second half were substantially lower than the first ten minutes of the second half.

PlayerLoad™·min^{-1} for the 5-minute periods are presented in Figure 3. In the first half, the 15-, 20-, and 30-minute periods were substantially lower than the previous periods combined, while the 35-minute period was substantially higher, also compared to the previous period (% likelihood of difference being higher/trivial/lower: 100.0/0.0/0.0 most likely). In the second half, the 10- and 30-minute periods were substantially lower than the previous periods combined. Second half values were substantially lower in the 10-minute (0.5/0.6/98.9, very likely), 25-minute (0.7/1.8/97.5, very likely), and 35-minute period (0.0/0.0/100.0, most likely), compared to the corresponding first half period.

Individual player analyses

Of the 81 peak periods for PlayerLoad™·min^{-1} in the initial analysis, 19 samples satisfied the inclusion criteria of a Pre, Post-5, and Post-10 period (Figure 4A and 4B). The Pre, Post-5, and Post-10 periods were all substantially lower than the peak period. The Post-5 period was also substantially lower than the Pre period. As 47% of peak-periods were observed in a player's first period of play, the sample was limited. When Pre was not accounted for (n=38), values for Peak were 120.0% (90% CL; ±2.5%), 100.2% (±3.1%) for Post-5 (0/0/100, most likely lower than Peak), and 95.9% (±2.5%) for Post-10 (0.0/0.0/100.0, most likely lower than Peak; 1.4/7.0/91.6, unclear difference from Post-5), compared to the 5-minute mean. Consequently, the decline was similar from the Peak to the Post-5 period in both analyses.

The effect of at least two consecutive periods of play on PlayerLoad™·min^{-1} is presented in Figure 5A and 5B. For outfield players combined, the second, third, fourth, sixth, and seventh consecutive period of play resulted in values substantially lower than all the previous periods combined. The second period was substantially lower than previous periods combined for backs and wings, the third for backs and pivots, the fourth for backs and wings, while the sixth period was substantially lower for wings and pivots.

Discussion

The main findings for team profiles were high initial values of PlayerLoad™·min^{-1}, declines throughout halves, and lower values in periods of the second half compared to the corresponding first half periods. The same patterns were observed in the position-specific analyses. A substantial increase in PlayerLoad™·min^{-1} was observed in the final 5-minute period of the first half, compared to the previous period. For individual players, analyses of the five minutes following the most intense period of the game indicated that PlayerLoad™·min^{-1} was below the players’ 5-minute average. Activity levels were partly restored ten minutes after the peak period, however, the Post-10 period was not substantially different from the Post-5 period. Furthermore, declines were observed in PlayerLoad™min^{-1} for individual players with two or more consecutive periods of playing time, for outfield players combined, and all positional categories.

Although Player Load™ is a particularly useful tool in frequent-contact sports, such as team handball[1,21], this is a relatively new field of study, and some caution must be taken when interpreting results. Specifically, the IMU-unit will not be able to detect isometric actions. Such actions are present in team handball, and thus, the intensity of team handball players might be somewhat underestimated by this method. To the author’s knowledge, no published study has validated the algorithm for team handball match play. However, Player

Load™ has been shown to be a reliable and useful measure of player activity in other team sports[10,17].

Team profiles

An elevated opening PlayerLoad™·min^{-1} is consistent with previous findings of high initial work rates from video-based analyses in team handball[2,3]. This has been suggested to indicate fatigue already in the first half, at least temporarily for full time players[2]. High intensities in the starting phase of team sports may be related to greater exercise economy at the start of matches, as reported in rugby league[16]. However, it is likely that situational factors play a large role in activity levels of team sport athletes. The high values of PlayerLoad™·min^{-1} observed could be related to suggested tactical enforcements by coaches[14], increased motivation and arousal[22], longer time of “ball in play”[16], or the rest period after the pre-game warm-up[14]. From a tactical standpoint, starting the game with a high intensity may be beneficial, as an early lead would put pressure on the opponents throughout the game. This may on the other hand cause players to fatigue earlier, as several studies have found that declines in activity levels are related to high work rates in previous stages of matches[15,23,24]. Intensity may also be down-regulated after an intense opening period in order to maintain an overall pacing strategy for the game, according to the pacing model proposed by Edwards and Noakes[25].

In the first 10-minute period of the second half mean PlayerLoad™·min^{-1} values were lower than in the first half. Interestingly, this period was the least intense of the whole game for wing players, with mean values below the match average, unlike the other positions. A lower starting intensity, compared to the first half, is similar to findings from video-based analyses of team handball[2,3] and GPS-based analyses of soccer[22]. In soccer, this has been suggested to only concern players with high work rates in the first half[15]. This could possibly explain the wing player profile, as these had the highest mean values in the first period of the first half. Different tactical dispositions with less involvement of the wingers may be an explanation, although this remains speculative. A less intense start of the second half in team sports could be an indication of fatigue caused by the first half, or could be due to a lack of re-warm-up after the half time break[2,3,15]. Pacing strategies may also be involved[15], as team sport athletes are suggested to re-evaluate their pacing strategy at half-time[25]. Still, one cannot exclude the possibility that high demands during the first half are responsible for physical performance declines across the whole second half, and not only towards the end[15].

Findings of lower intensities for second half periods can be associated with previous observations of decreases between halves and throughout periods in team handball[2,3,5,7]. This is possibly attributed to physical impairment of players, and a consequent inability to work at the desired rate. This is supported by findings of decreased physical performance[7-9] and suggested changes in muscle structure following team handball games[8], which have been linked to lower team activity in team handball games[2,3,7-9]. A reduced intensity in the second half of team sports could also be caused by a mismatch between game demands and physical fitness[10,26], where players start the game at an intensity which is too high to maintain for a whole match. This is especially relevant in national teams, where players often have less experience with the competition demands[8]. It is also in line with Edwards and Noakes' pacing theory, where knowledge of energy demands and previous experience is an important determinant for setting an appropriate pacing strategy[25].

Inconsistent decrements were observed for activity levels in the present study, and have been reported from physical performance tests following team handball games in previous studies[7,8]. This suggests rotation strategies and interchanges can be sufficient to maintain the physical capacity of team handball players during matches, and especially of the team as a whole. However, these were international matches, and the substitution strategies may differ during major tournaments, such as the World Championships and Olympics. This aspect would clearly be useful to examine in regard to activity profiles and possible fatiguing, but would require a deeper insight into to the game plans and tactics.

In some team sport matches results could be decided already early in the second half, and as such, goal difference could impact the pacing strategies of players, with players reducing their effort with a comfortable lead or a perceived certain loss. Score line has previously been suggested to affect physical performance and pacing strategies in other team sports[15,27]. Weaker or less fit players may also be introduced into the games in the later stages, and coaches could experiment with new tactics and formations. Furthermore, two-minute suspensions lead to frequent periods of play with an uneven number of players on each team, and injuries, floor-mopping and other stoppages could lead to longer breaks in the game, possibly affecting activity profiles of players. Although these are possible factors affecting team activity and causing apparent team fatigue, they were not examined in this study. Therefore, these aforementioned factors remain speculative, requiring further examination in future studies.

It must be emphasized that the observed matches were played in a congested schedule, with four games in three days. As previous research has suggested that even 48 hours rest is not sufficient to fully recover from intense team handball play[8], the current analyses might not truly represent a single championship match. As such, the effect of fatigue from previous matches on activity profiles is unclear, and would be highly relevant for practical application of the current results. This is of special relevance as international championships are often played with games every second day. In junior rugby league, players have shown to pace their effort in order to enhance performance in a four-day tournament[26], further highlighting this issue.

With declining activity levels between and during halves, one would expect the final periods to show the lowest PlayerLoad™·min^{-1}. This was also true for the final 10-minute period of the second half. However, the final 5-minute period of the first half was substantially higher than the previous period and all previous periods combined, and a non-substantial increase (unclear, 85.9/8.7/5.4) was observed in the final period of the second half. This phenomenon has previously been observed in the final minutes of team handball matches[2], and may be caused by players reducing their effort during the second half in order to increase the tactical and physical performance in the closing minutes[2]. Alternatively, increased motivation and more active coaching could be a factor, as has been suggested for the opening periods. Increases in activity levels may indicate that players were not completely physically exhausted in the final stages. The observed increases may therefore suggest that pacing strategies are adopted by players and teams, either consciously or subconsciously, on a tactical or physical level. This could result in an "end spurt", which has been observed in other team sports[28]. Alternatively, it could be that players on the field towards the end of games were interchanged players. Interchanged or substituted players in team sports have been reported to work at higher intensities than whole-game players[15,27,29], possibly due to differences in pacing strategies compared to whole-game players[27,28].

Player profiles

The findings of the present study suggest team handball players experience substantial declines in PlayerLoad™·min^{-1}, with values below the 5-minute average, in the Post-5 period. Values were partly restored in the Post-10 period, compared to the 5-minute average, possibly indicating the occurrence of transient fatigue in team handball. This has not previously been reported for team handball players, but is similar to findings from studies in soccer using GPS- and video-based analyses[14,15].

The observed declines following the most intense period may be caused by insufficient rest periods in certain periods of the match. The mean time between changes of high- and low-intensity activity in team handball games has been reported to be 55 seconds[3], while one third of rest periods between intense runs have been found to be under 30 seconds[7]. This could hinder recovery of energy stores and force-production conditions[3], as half-time for PCr resynthesis is suggested to be between 21-57 seconds[30]. Alternatively, transient declines in team sports have been suggested to be caused by "micro" pacing strategies[28]. If this is true, periods of play with lower intensity after peak periods may be a protective strategy aiming to maintain an overall pacing strategy for the game or half[25]. Situational factors may also be implicated, and the declines could simply be a result of variations in game dynamics and the intermittent nature of team sports. In support of this, time of "ball in play" has been reported to be longer in the peak periods of soccer games, suggesting players have more opportunities to play than in the other periods[31].

The highest value of PlayerLoad·min^{-1} for players with consecutive periods of field time was found in the first period of play. This is similar to what was observed in the team profile, and as discussed, it may be attributed to situational variables rather than to the subsequent declines. In the present study, the first period of field time could be at any point of the match. Consequently, one possible explanation is that players are more motivated and active, wanting to make an impact, as soon as they are introduced into the match, irrespective of match time.

Decreases in PlayerLoad™·min^{-1} with two or more consecutive periods of play is in line with the previously discussed declines in team activity levels. This is likely to be caused by either fatiguing of neuromuscular systems or pacing strategies. The profile for individual players has similar characteristics to a "slow-positive" pacing profile of whole-game players in team sports, with progressive declines in intensity across a match[28]. These findings also further strengthen the suggestion that declines in activity levels on a team level are partly explained by declines in individual player activity. Furthermore, the observed decreases may suggest that playing intensity is not sustained with longer periods of field time. This can be indicative of match-induced fatigue in players who play large parts of halves without rest periods. Possibly, the unlimited interchange rule can lead to players positively altering their pacing strategies, as they know that they can be replaced if they are fatiguing[28].

Practical Applications

The results from the present study are of interest to coaches and trainers, aiming to reduce declines in activity levels through design of effective training programs and rotation strategies. If PlayerLoad™·min^{-1} is closely linked with overall performance, this could prove a highly relevant variable to monitor in real-time during team handball matches. To limit the decreases in activity after intense periods, improving anaerobic capacity and repeated sprinting ability may be beneficial[3]. As the highest activity is observed in the first period of play, this can be used tactically by coaches, by introducing rested "impact players" in certain periods of the game in order to raise the intensity on the field[32].

Future studies should include thorough examinations of underlying mechanisms, including measures of internal load, pacing strategies, interchanges, situational factors, and physiological variables. Studies aimed at associating PlayerLoad™·min^{-1} to overall team handball performance would also be highly relevant for practical application of data. Differences in female and male activity profiles should be further examined, and caution must be taken when transferring the current results to male teams and players.

Conclusions

In conclusion, the results of the present study suggest that activity levels, as measured by PlayerLoad™·min^{-1} using modern micro technology, are not sustained throughout matches in female team handball, although an increase at the end of the first half was observed, compared to the previous period. Furthermore, team and positional profiles were characterized by an intense first ten minutes of play. Individual player analyses indicated a substantial drop in activity levels five minutes after the most intense period of play compared to average values, and values were partly restored in the subsequent five minutes. A high first period of play was observed, followed by substantial declines in activity levels with two or more consecutive periods of play, for outfield players combined and all positional categories. These results could be indicative of fatigue in female team handball teams and players, although this can not be assumed based on this study alone, with only one measure of external loading. Situational factors or pacing strategies may be implicated, although underlying mechanisms were not examined in this study.

Acknowledgements

The authors would like to thank the Norwegian Handball Federation, and especially the women's national team, for their participation and interest in this project. The results of the current study do not constitute endorsement of the product by the authors or the journal.

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Figure 1 Timeline, displaying the matches played in the 2014/2015 Golden League tournament-series, including rest days and time between each tournament.

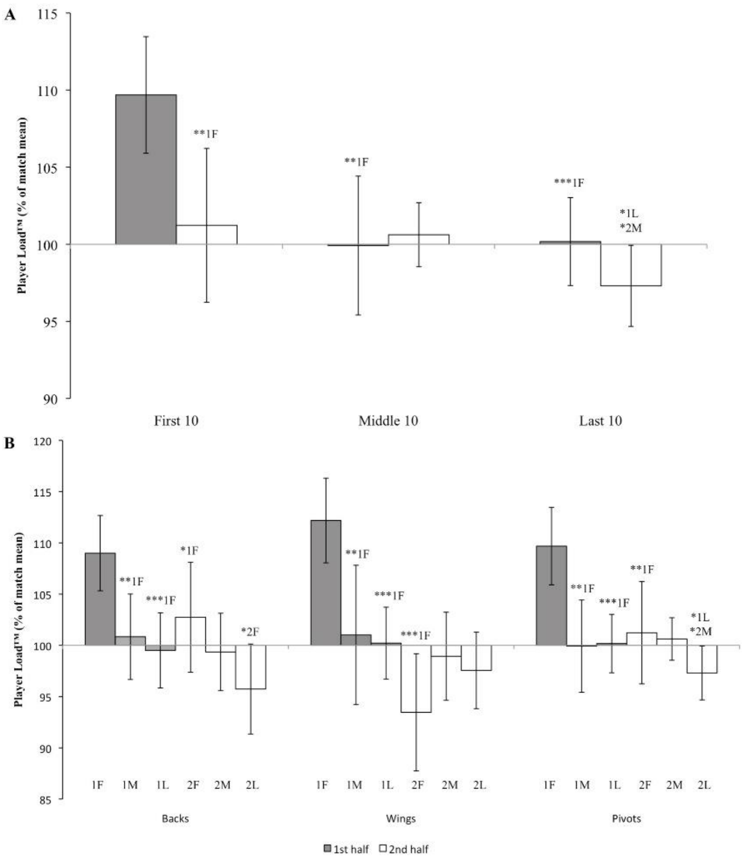

Figure 2 Team PlayerLoad™·min^{-1} in 10-minute periods, presented as percentage of match mean ±90% CL (n=9 matches) for outfield positions combined (Figure 2A), and each positional category (Figure 2B). Substantial differences between and within halves were either likely (*), very likely (**), or most likely (***). 1F = First half, first period, 1M = First half, middle period, 1L = First half, last period, 2F = Second half, first period, 2M = Second half, middle period, and 2L = Second half, last period.

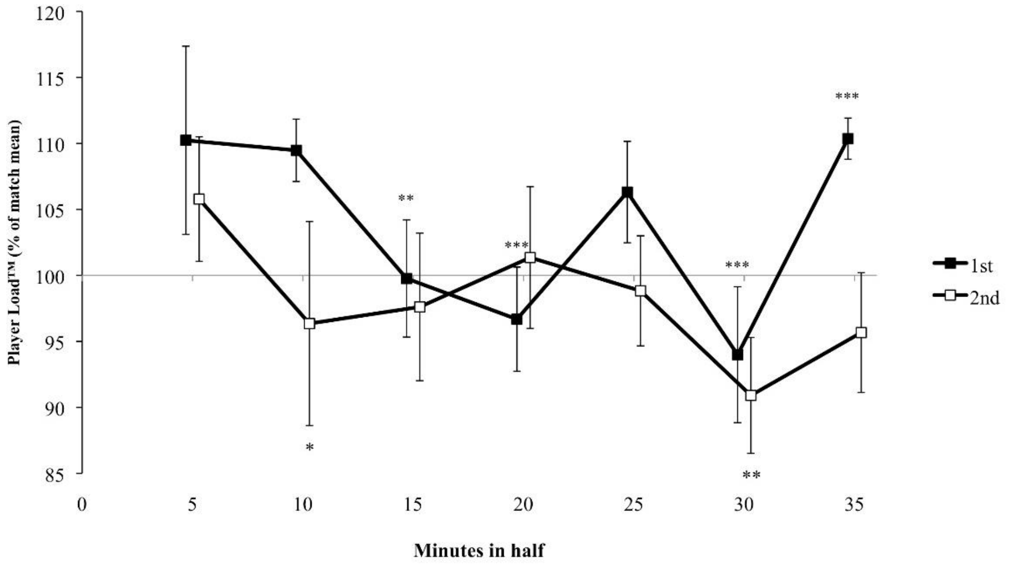

Figure 3 Team PlayerLoad™·min^{-1} in 5-minute periods, presented as percentage of match mean ±90% CL (n=9 matches). Due to differences in half duration, the 35-minute period does not include all nine matches (1st: n=4 matches; 2nd: n=8 matches). Substantial differences, compared to all previous periods in the half combined, were either likely (*), very likely (**), or most likely (***).

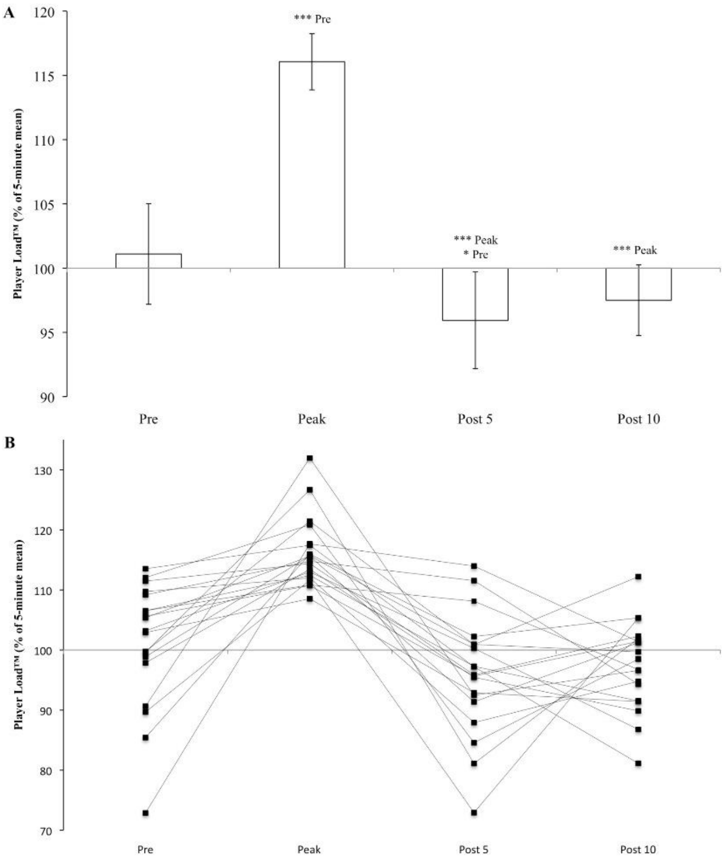

Figure 4 Percentage of 5-minute mean for PlayerLoad™·min^{-1} ±90% CL for individual players (n=19 samples). Figure 4A represents mean values, while Figure 4B provides more detailed information on individual player variation. Periods are the most intense 5-minute period (Peak), the 5-minute period preceding (Pre), and the two 5-minute periods following (Post-5 and Post-10) the peak. Substantial differences compared to previous periods were either likely (*), very likely (**), or most likely (***).

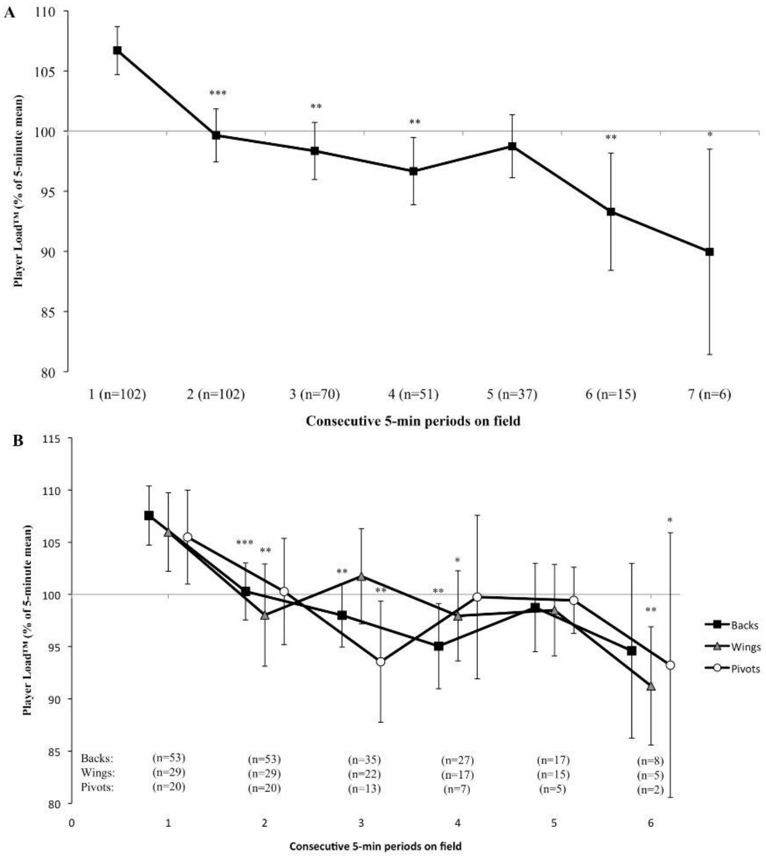

Figure 5 Percentage of 5-minute mean ±90 CL for PlayerLoad™·min^{-1} for individual players with minimum two consecutive 5-minute periods of play. Figure 5A represents all outfield players combined (n=102 samples), while Figure 5B is position specific (n=53 back, 29 wing and 20 pivot samples). Each player could be represented with one sample from each half. Substantial differences compared to all previous periods combined were either likely (*), very likely (**), or most likely (***).

Table 1 Mean values for outfield players combined and positional categories, for PlayerLoad™·min^{-1} and field time. Includes all data samples with a minimum of one minute of field time, in at least one 5- or 10-minute period of the game.

	Outfield players	**Backs**	**Wings**	**Pivots**
n	85	46	24	15
n pr. game ± SD	9.4 ± 1.6	5.1 ±1.1	2.7 ± 0.5	1.7 ±0.5
Age ± SD	25.4 ± 3.8	26.0 ± 4.1	25.1 ± 3.8	24.3 ± 2.9
Player Load™·min^{-1} ± SD	9.52 ± 1.1	9.76 ± 1.4	9.18 ± 0.6	9.31 ± 0.8
Field time pr. game (min) ± SD	29.3 ±14.6	28.7 ±15.0	29.5 ±14.1	30.9 ±14.6

Table 2 Match scoring details, with mean goals scored and conceded in each half and mean goal difference.

	Mean	**SD**	**Min**	**Max**
1st half goals scored	12.6	2.4	8	16
2nd half goals scored	12.9	3.4	9	18
Full time goals scored	25.4	4.4	21	32
1st half goals conceded	12.4	2.2	9	16
2nd half goals conceded	10.7	3.4	6	15
Full time goals conceded	23.1	4.5	15	28
Goal difference	2.3	6.2	-5	12