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The Physical and Physiological Demands of Elite International Female Field Hockey Players During Competitive Match-Play

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ABSTRACT

The aim of the current investigation was to quantify the physical and physiological demands of elite international female field hockey match-play across halves of play. Thirty-eight participants (24 ± 5 years; 173 ± 5 cm; 72 ± 5 kg) took part in nineteen competitive matches during the 2014 – 2015 season. Participants were monitored with GPS technology and heart rate monitors. Players were categorized based on three different playing positions. Activity was categorized into total (m), high-speed running distance (m; >16 $km\cdot h^{-1}$) and relative distance ($m\cdot min^{-1}$) due to the use of rolling substitutions. Heart rate was classified based on the percentage of players individual HR_{peak} determined via a Yo-Yo intermittent recovery level 1 test. Players spent on average 44 ± 7 min in match-play. The total distance covered was 5558 ± 527 m (125 ± 23 $m\cdot min^{-1}$) with 589 ± 160 m (13 ± 4 $m\cdot min^{-1}$) completed at high-speed. Defenders covered a greater total distance compared to other positions of play ($p \leq 0.001$). Midfield players covered a greater distance at high-speed ($p \leq 0.001$) with the forwards having a higher relative distance ($p \leq 0.001$). The HR_{peak} of the players was 199 ± 1 $b\cdot min^{-1}$ with a mean exercise intensity of 86 ± 7.8 % of HR_{peak}. The time spent >85% HR_{peak} decreased significantly across the halves ($p = 0.04$, $\eta^2 = 0.09$, Small). Defenders were found to spend more time >85 % HR_{peak} when compared to forwards ($p \leq 0.001$). The current investigation provides normative data that coaches should consider when constructing training regimen.

Key Words: Team Sports, GPS, Heart Rate, Intermittent Activity

INTRODUCTION

Field hockey is a stick and ball team sport where the movement patterns of players are stochastic in nature following the ebb and flow of competitive match-play (7,16,33). Competitive match-play consists of two 35 min halves with two teams of eleven players consisting of a goalkeeper and ten outfield players. The sport requires players to engage in high-speed running intertwined with accelerations, decelerations and changes of direction. Players execute unorthodox offensive and defensive skills in condensed areas during match-play with the aim of match-play to outscore the opposition (10). The international field hockey season takes place over a nine-month period. The premier competitions of interest are the World League and World Cup which provide a path for teams to qualify for the Olympic Games. Despite the ever increasing popularity of field hockey there is a paucity of published material on the overall demands of the game at an international level (7,16,23,33).

The use of global positioning systems (GPS) technology has become increasingly popular with these systems utilized during training and match-play in the majority of team sports (19). The technology has allowed the physical demands of training and match play in female hockey to be observed providing coaches with the necessary data to construct training regimen that best replicate these demands (7,16,33). The utilization of these systems allows for the accurate measurement of physical demands across speed dependent zones of movement (7,16,18,19). Global positioning systems have previously been used to quantify the physical demands of many female field based sports such as soccer (18), rugby union (35) and rugby 7's (34). A recent review by McFarlane and colleagues (19) showed GPS technology to be the superior choice in athlete monitoring in comparison with other methods such as time motion and hand notation analysis. The technology provides quantitative analysis on the movement demands of match-play which can be vital for the construction and monitoring of training plans (19).

Field hockey, like other team sports has a degree of positional variation with regard to the physical demands (18,20,31,34). Research relating to female game is limited (14–16,29,33). Jennings et al. (10) observed that with the roll-on roll-off nature of the game, the high number of substitutions should be taken into consideration when interpreting the differences between positional lines of play. The continuous substitution rule means that players spend on average 48 minutes on the pitch during the whole 70 minute duration of match play and typically cover 5541 ± 1144 m (16). Typically, defenders have been shown to cover greater total distances (TD) (6170 – 6643 m) when contrasted against forwards (4700 - 6154 m) and midfielders (5626 - 6931 m). Meanwhile, forwards have been observed to complete higher relative distance (RD) of between 70 – 124 $m \cdot min^{-1}$ when compared to the defenders and midfield players (79 – 110 $m \cdot min^{-1}$; 79 - 113 $m \cdot min^{-1}$) (7,16,33). Vescovi and Frayne (33) have suggested that differences in playing time can effect high-speed distance (HSD), with Macutkiewicz and Sunderland (16) observing that forwards spent more time performing high-intensity exercise (8 %) when compared to midfielders (6 %) and defenders (5 %).

By identifying the physical and physiological demands a coherent profile of match-play can be determined and used to aid coaching practice (9,15,20). Despite the intermittent nature of the match-play the monitoring of heart rate (HR) responses provides reliable information on the physiological strain experienced during match-play (13). A limitation of current physiological research is that it is restricted to general HR values rather than time spent in different exercise intensity zones (11,16,29) as such they fail to provide coaches with actionable data with regard to the specific breakdown of the intensity during match play. The average HR of players during match-play has been reported as 174 ± 11 $b \cdot min^{-1}$ (15,16,18), with MacLeod et al. (14) observing a decrease in HR across the halves. The observed decrease in exercise intensity has been related to pacing or tactical changes (2,13,16,31). Currently literature profiling the positional physiological demands during match-play are limited (29). Macutkiewicz and Sunderland (16) were the first to report differences across the positions at an elite level. The study reported that forwards experienced higher intensities than the midfield and defenders during match-play with forwards while also having significantly less time to recover between these high-intensity bouts. However, within men's hockey Lythe and Kilding (13) concluded that the unlimited number of substitutions allows the forwards increased time to recover during competitive play, thus allowing these players to repeatedly perform high-intensity efforts (13). Sell and Ledesma (29) reported conflicting results to Macutkiewicz and Sunderland (16) suggesting that within female hockey midfield players spend a higher percentage of game time at higher intensities. While the results of these studies are conflicting, they suggest that a positional variation during hockey match-play is apparent and needs to be considered and understood by coaches during the construction of training drills.

Research conducted on elite international female field hockey cohorts is limited (16,23,33). Therefore, an updated examination of physical and physiological responses during match-play is warranted to allow practitioners to construct training methodologies that best replicate the current positional demand of international competition. Given the above, the primary aim of the current investigation was to quantify the physical and physiological demands of elite international female hockey players during competitive match-play. Furthermore, we aimed to determine the position specific differences in physical and physiological profiles across halves of play. It was hypothesized that defenders would cover greater TD; midfielders would cover more high-speed distance (HSD) while the forwards who spend the least amount of time in competitive match-play would be seen to have a higher relative distance (RD) output. It was expected that female field hockey would be played at a low to moderate intensity (7,18) with limited time > 85 % HR_{peak}.

METHODS

Experimental approach to the problem

The current observational study was designed to examine the physical and physiological demands of elite international female field hockey players using portable GPS technology (4-Hz, VXsport, Lower Hutt, New Zealand) and HR monitors (Polar Team 2, Polar Electro Oy, Kempele, Finland) across halves of match-play. Prior to match-play data collection, participants performed a Yo-Yo intermittent recovery test level 1 (Yo-YoIR1) to identify each players speed threshold and heart rate max (HR_{max}). Thirty-eight elite international female field hockey players were observed during nineteen competitive games over the 2014 – 2015 international season. Across the observational period both test series and International Hockey Federation ranked games were played against opponents with a world ranking ranging from four to thirty-four. Players were categorized based on positional line of play (defender, midfielder and forward). HR was recorded via short range radio telemetry. Game data was only included if the player was to play a minimum of ten minutes in both halves of competitive match-play. Research has shown that the maximum speed capabilities of females to be lower then males, therefore it is recommended that female-specific speed thresholds be established for the analysis of the physical demands (4). Previous research has suggested that repeated bouts of high-speed during match-play is associated with elevation in blood lactate accumulation (3,4). During the Yo-YoIR1 players achieved maximum distances ranging between 1600 – 1920 m (17.5 – 18.5 km·h^{-1}). Given that high-speed should be above the onset of blood lactate accumulation, generic high-speed thresholds were set at 90 % which equated to 16 km·h^{-1}. All competitive matches took place between 14.00 and 20.00 hours. Prior to match-play (24 - 48 hours) players were requested to abstain from strenuous physical activity and were advised to maintain their normal diet, with special emphasis being placed on the intake of fluids and carbohydrates.

Subjects

Thirty-eight elite international female field hockey outfield players (24 ± 5 years; 163 ± 5 cm; 64 ± 5 kg) participated in the current study. Players were selected as they were members of the country's national hockey squad that season, therefore were deemed the best players in the country at the time of data collection. After ethical approval, participants attended an information evening where they were briefed about the purpose, benefits, and procedures of the study. Written informed consent and medical declaration were obtained from participants in line with the procedures set by the local institution's research ethics committee

Physical Demands

The participants wore an individual GPS unit (VXsport, Lower Hutt, New Zealand, Issue: 330a, Firmware: 3.26.7.0) sampling at 4-Hz and containing a triaxial accelerometer and magnetometers in a total of 30 games. The GPS unit (mass: 76 g; 48 mm x 20 mm x 87 mm) was encased within a protective harness between the player's shoulder blades in the upper thoracic-spine region this ensured that players' range of movement in the upper limbs and torso was not restricted. Prior to the GPS being inserted into the harness, the devices were turned on and a satellite connection was established fifteen minutes before the warm up. The GPS data was extracted from each device using proprietary software (VXsport View, New Zealand). Given the use of rolling substitutes the time each participant spent in match-play was noted to accurately track the players physical and physiological demands for a given game. The data was analyzed retrospectively and exported to Microsoft Excel (Microsoft, Redmond, USA) this allowed for further in-depth analysis. Physical demands were classified based on distance covered across four zones adapted from those recently used in female field hockey (33). Zone 1 (0-7.9 km·h^{-1}), zone 2 (8-15.9 km·h^{-1}), zone 3 (16-19.9 km·h^{-1}) and zone 4 (> 20 km·h^{-1}). Other variables of interest included relative total distance (RTD) (m·min^{-1});

relative high-speed distance (RHSD) ($m \cdot min^{-1}$; >16 $km \cdot h^{-1}$). The coefficient of variation (CV %) of the GPS unit during intermittent exercise has previously been reported as 1.0 – 8.0 %. (17)

Physiological Demands

Physiological demands during match-play were assessed based on HR analysis, which was recorded every 5 seconds using a telemetric device (Polar Team Sport System 2; Polar Electro Oy, Kempele, Finland). The highest HR value reached during the Yo-YoIR1 was taken as the players peak heart rate (HR_{peak}). The test selected was part of the team's regular performance testing regime and all players were familiar with the methods. Participants were provided with a heart rate monitor (Polar Team 2, Polar Electro Oy, Kempele, Finland), which was secured with a chest strap. Players exercise intensity was spilt into four zones adapted from those recently used in female field sports (26,29,30). Zone 1 (< 69 % HR_{peak}), zone 2 (70 - 84 % HR_{peak}), zone 3 (85 - 89 % HR_{peak}) and zone 4 (> 90 % HR_{peak}). Other variables of interest included HR_{peak} and mean heart rate (HR_{mean}). The HR_{peak} was subsequently used during competitive match-play with values calculated as a percentage of this figure. The HR_{mean} for each match were recorded and expressed as a percentage of individual HR_{peak} to provide an indication of the overall intensity of the match in relation to the HR_{mean} and HR_{peak} during match-play. Data was downloaded and analyzed retrospectively (Polar Precision Performance v4.03.043) and exported to a customized excel file. The CV % of HR response during intermittent exercise has previously been reported as 1.3 – 4.8 % (12,28).

Statistical Analysis

Data is presented as means ± standard deviation with 95 % confidence intervals (95 % CIs) and effect size, partial Eta-squared (η^2). Any data that was not normally distributed was removed from data analysis. A multivariate analysis of variance (MANOVA was used to examine the difference between positional groups (3) and halves of play (2). The dependent variables across the range of analysis were, TD (m); HSD (m; >16 $km \cdot h^{-1}$), RTD ($m \cdot min^{-1}$); RHSD ($m \cdot min^{-1}$; >16 $km \cdot h^{-1}$), average HR_{max} and percentage HR_{max} with playing position and match-play periods (e.g, first and second half) independent variables. Standardized effect sizes (ES) were reported as partial eta squared (η^2) with effects defined as small 0.01 – 0.08, medium 0.09 – 0.24 and large > 0.25. Statistical significance was accepted at $p \leq 0.05$. SPSS Version 22.0 (IBM Corporation, New York, USA) software were used to analyze the data.

RESULTS

Physical Demands

The time spent in competitive match-play was 44 ± 7 min (95 % CI: 36 – 52 min) which accounted for 63 % of game time. The time on field remained the same across the halves regardless of position (22 ± 4 min). The physical demands observed during match-play are presented in Table 1. The TD covered regardless of position was 5558 ± 527 m (95 % CI: 5353 – 5740 m). A non-significant difference in TD was observed ($p = 0.6$; $\eta^2 = 0.01$; Small) between the first (2820 ± 266 m; 95 % CI: 1971 – 3455 m) and second half (2705 ± 300 m; 95 % CI: 1992 – 3351 m). The RTD observed was 125 ± 23 $m \cdot min^{-1}$ (95 % CI: 125 – 127 $m \cdot min^{-1}$) regardless of position. The RTD covered by players decreased between the first (128 ± 10 $m \cdot min^{-1}$) and second (123 ± 13 $m \cdot min^{-1}$) halves, although this difference was non-significant ($p = 0.5$; $\eta^2 = 0.4$; Large) (Figure 1). The RHSD was 13 ± 4 $m \cdot min^{-1}$ (95 % CI: 5 – 20 $m \cdot min^{-1}$) irrespective of position, with no differences observed ($p = 0.5$; $\eta^2 = 0.4$; Large) across the halves (14 ± 4 $m \cdot min^{-1}$, 95 % CI: 6 – 20 $m \cdot min^{-1}$; 13 ± 5 $m \cdot min^{-1}$, 95 % CI: 5 – 29 $m \cdot min^{-1}$) (Figure 2).

INSERT TABLE 1 NEAR HERE

Positional Physical Demands

A significant difference across positions ($p = 0.001$; $\eta^2 = 0.3$; Large) was observed for the time spent in match-play, with defenders (50 ± 8 min, 95 % CI: 40 – 60 min) spending more time in play when compared to midfielders (43 ± 5min, 95 % CI: 37 – 49 min) and forwards (41 ± 6 min, 95 % CI: 34 – 51 min) respectively. When TD was considered, a significant difference ($p = 0.001$; $\eta^2 = 0.58$; Large) was observed across the positional lines of play (defender: 5696 ± 530 m, 95 % CI: 4942 – 6574 m; midfielder: 5555 ± 456 m, 95 % CI: 4939 – 6160 m; forward: 5369 ± 578 m, 95 % CI: 4300 – 6185 m). Furthermore, significant positional differences were observed for HSD ($p = 0.001$; $\eta^2 = 0.41$; Large). These differences resulted in defenders covering more TD while midfielders were observed to cover significantly more HSD.

When RTD was considered (Figure 1) the forwards (131 ± 10 m·min^{-1}, 95 % CI: 116 – 146 m·min^{-1}) and midfielders (129 ± 5 min^{-1}, 95 % CI: 121 – 138 m·min^{-1}) covered higher RTD when compared to defenders (114 ± 7 m·min^{-1}; 95 % CI: 103 – 123 m·min^{-1}) respectively ($p = 0.001$; $\eta^2 = 0.5$; Large). Similarly, significant positional differences were observed for the RHSD ($p = 0.001$, $\eta^2 = 0.3$, Large) with midfielders (16 ± 3 m·min^{-1}, 95 % CI: 12 – 18 m·min^{-1}) and forwards (15 ± 5 m·min^{-1}, 95 % CI: 9 – 17 m·min^{-1}) covering a RHSD (>16 km·h^{-1}) than defenders (10 ± 2 m·min^{-1}, 95 % CI: 6 – 22 m·min^{-1}) during match-play ($p = 0.001$) (Figure 2).

Physiological Demands

The HR_{peak} during match play was 199 ± 1 b·min^{-1} with the HR_{mean} of 171 ± 1 b·min^{-1}, reflective of an average exercise intensity (Table 2) regardless of position of 86 ± 8 % HR_{peak} (95 % CI: 82 – 91% HR_{peak}). HR increased from 85 ± 11 % HR_{peak} (95 % CI: 82 – 90% HR_{peak}) to 87 ± 2 % HR_{peak} (95 % CI: 84 – 91% HR_{max}) across the halves, however this variation was non-significant ($p = 0.4$; $\eta^2 = 0.02$; Small). The HR_{peak} during competitive match-play was 96 ± 4 % HR_{peak} (95 % CI: 92 - 98% HR_{peak}), (Table 2). Players spent on average 71 ± 8 % of competitive match-play engaged in exercise > 85 % HR_{peak}. The time spent > 85 % HR_{peak} decreased significantly between the first (16 ± 3 min) and second halves (15 ± 3 min) ($p = 0.04$; $\eta^2 = 0.09$; Medium) (Table 2).

INSERT TABLE 2 NEAR HERE

Positional Physiological Demands

No significant difference was observed in HR_{mean} when considered, relative to the HR_{peak} ($p = 0.4$; $\eta^2 = 0.04$; Small) during match-play. Specifically, the HR_{peak} across positions were as follows: defenders 86 ± 2 % HR_{peak} (95 % CI: 85 - 91% HR_{peak}), midfielders 87 ± 2 % HR_{peak} (95 % CI: 82 - 89% HR_{peak}) and forwards 85 ± 12 % HR_{peak} (95 % CI: 82 - 90% HR_{peak}). When HR_{peak} during match play was considered non-significant differences across positions were observed ($p = 0.36$; $\eta^2 = 0.05$; Small). Specifically, defenders 96 ± 1 % HR_{peak} (95 % CI: 94 – 97 % HR_{peak}), midfielders 96 ± 6 % HR_{peak} (95 % CI: 93 – 97 % HR_{peak}), forwards 95 ± 1 % HR_{peak} (95 % CI: 92 – 98 % HR_{peak}). When time spent > 85 % HR_{peak} was considered, significant differences were found across the positions ($p = 0.001$; $\eta^2 = 0.22$; Medium). Defenders (35 ± 3 min; 95 % CI: 31 – 41 min) were shown to spent a significantly greater time > 85 % HR_{peak} than the forwards (29 ± 3 min; 95 % CI: 22 -34 min) and midfielders (32 ± 7 min; 95 % CI: 24 – 45 min) ($p = 0.001$; $\eta^2 = 0.22$; Medium) (Figure 3).

DISCUSSION

The primary aim of the current investigation was to quantify the physical and physiological demands of elite international female hockey players during match play. Furthermore, we aimed to determine the positional differences in physical and physiological demands across halves of play. Our data shows that substantial differences in physical demands across positional lines of play exist. Furthermore, reductions in RTD and RHSD were detected between the halves. Finally, we reported reductions in physiological demands across halves of play with a positional profile observed for HR_{peak} and time spent > 85 % HR_{peak} . The current study is one of the first to observe significant differentiation in both the physical and physiological profiles across halves of play and positional lines during elite international female hockey match-play.

Our data shows that elite female field hockey players regardless of position spent 44 ± 7 min in competitive match-play. Players were shown to cover a TD of 5540 ± 521 m (126 ± 23 $m \cdot min^{-1}$), with 589 ± 160 (13 ± 9 $m \cdot min^{-1}$) covered at HSD regardless of playing position. The observed mean playing time of 44 ± 7 min agrees with that previously reported by Macutkiewicz and Sunderland (16) of 48 ± 4 min. However, these observations are lower than those previously reported (33) (62.5 ± 12.8 min). Indeed, the analysis conducted by Vescovi and Franye was completed on collegiate athletes, which may explain the discrepancy observed. The TD covered during match-play was similar to that reported by Macutkiewicz and Sunderland (16) (5541 ± 1144 m) but lower than that reported by Vescovi and Franye (33) (6461 ± 1294 m). The RTD of 103 $m \cdot min^{-1}$ was less than that reported in the current study which suggest that elite field hockey players cover distance at increased relative intensity when compare to collegiate athletes. Furthermore, the relative data reported in the current study is in agreement with previous analyses on female hockey cohorts (16) .

INSERT FIGURE 1 NEAR HERE

Previous studies examining team sports have shown that a team's success can be related to time in possession of the ball and the ability to cover HSD (1,8). The results of the current study suggested that regardless of position, players covered 589 ± 160 m reflective of 13 ± 9 $m \cdot min^{-1}$ at HS (m; >16 $km \cdot h^{-1}$). Vescovi and Franye (27) recently reported a slightly higher HSD (m; >16 $km \cdot h^{-1}$) during match-play of 631 ± 173 m (10 $m \cdot min^{-1}$). Anderson et al. (1) showed that female athletes performed more HSD during international match-play than during domestic match-play respectively. Although the current study suggest that elite players cover less HSD during match-play they were shown to cover more RHSD then that previously reported for domestic players (1). However, Macutkiewicz and Sunderland (16) reported the average HSD (m; >15.1 $km \cdot h^{-1}$) covered by players was 852 ± 268 m (17.8 ± 67 $m \cdot min^{-1}$). However, differences in selected speed thresholds across research make it hard to compare results. The differences in RTD and RHSD outputs may be reflective of the influence that the rolling substitution rule has on the game. The observed data may inform coaches of potential strategies to maximize this rule by employing a specific rolling substitute policy based on GPS and HR data of players. Indeed, coaches may decide to make substitutions based on reductions in HSD and RHSD given that these variables have been previously linked to technical outputs during match-play (8).

** INSERT FIGURE 2 NEAR HERE **

Monitoring HR responses during match-play provides an indication of the internal physiological load during game play actions (32). The HR_{peak} of the players was 199 ± 1 $b \cdot min^{-1}$ with the HR during match-play of 171 ± 1 $b \cdot min^{-1}$ reflective of an average exercise intensity regardless of position of 86 ± 8 % HR_{peak}. During competitive match-play players had a HR_{peak} of 96 ± 3.5 %. Sell and Ledesma (29) examined HR responses in NCAA division I colligate female hockey players and reported HR_{peak} responses of 94.6 ± 3.3 %. Regardless of position Sell and Ledesma (29) reported the HR_{peak} of international female hockey players was 203 ± 7 $b \cdot min^{-1}$ which is higher than previously observed by MacLeod et al. (15) (190 ± 9 $b \cdot min^{-1}$) and our current observations. The time spent > 85 % HR_{peak} has been previously shown to be associated with improvements in aerobic capacity while also being linked to an improved physical activity profile during match play (9,23). Therefore, it is important for coaches to monitor the time spent > 85% HR_{peak} to best ensure players attain these intensities during training, this will ultimately best equip them to compete during match-play. The players in the current investigation spent on average 31 min > 85% HR_{peak} suggesting that a high percentage of match-play is played at high-intensity.

** INSERT FIGURE 3 NEAR HERE **

The current data will allow coaches to prepare training scenarios for players to reach these higher intensities. It may be suggested that larger small-sided game pitch dimensions with high relative player areas will best allow for these higher intensities to be achieved (24). However, careful consideration must be given to the external factors that may influence HR responses such as playing level, opposition and environmental factors (32). Previous research has shown field hockey to be of a low – moderate intensity (7,16,33). The intermittent nature of the game and limited number of stoppages and limited opportunity to recover between high-speed efforts. The current study supports the literature suggesting the need for an increased focus towards aerobic conditioning to adequately prepare players to recover between high-speed efforts (10,29). Future investigations should aim to identify potential training methodologies that can improve aerobic capacity in elite female hockey players.

It has been suggested that players will regulate distance travelled at low-speed to ensure they have the ability to produce high-speed efforts when required during match-play (2). Our data showed there to be no significant difference in physical demands across the halves of play in elite female hockey. Interestingly, the observed decrements in physical activity were position specific with the defenders showing the highest level of reduction across the halves when compared to other positions. Defenders were shown to have on average a 5% decrease in RTD and significant reduction of 10 % in RHSD across halves of play. Midfielders increased the RTD and RHSD covered by 2 % across halves, while forwards were shown to increase the RTD covered by 1% with no change in RHSD. The findings of the current study differ to those by Vescovi and Frayne (33) suggesting that in collegiate female hockey both the defenders and midfield players would cover less RTD and RHSD across halves of play. Although the results of the current study show there to be a non-significant difference, in a sport setting a 5% decrement in performance could be deemed a practical significant decrease in HSD covered. Previous studies have shown that the most successful teams cover a greater HSD and sprint distance (8,27). The findings of the current study show that positional roles influence physical activity during female hockey match-play.

However, it is unclear whether the reduction is based on fatigue, tactical factors or physiological factors (2,21,32). Keeping this in mind, having a clear and concise substitution policy within the squad could reduce fatigue due to increased recovery between bouts of play and in-turn reduce the effect of positional demands on the physical activity profiles of players.

INSERT FIGURE 4 NEAR HERE

Previous studies have attempted to analyze the positional profile of female field hockey across various competitive standards (7,16,29,33). Similar to previous studies in female soccer (18,20), rugby union (31,35) and rugby 7's (34) a position specific profile was observed for female hockey players. Specifically, defenders spend significantly more time in match-play and covered more TD than other positions. However, when the relative outputs were considered the midfield and forwards had significantly higher relative intensities for physical activity. Notably, midfielder's due to their nomadic nature covered more HSD, this may be related to the fact that these players provide a tactical link between defence and attack when in and out of possession. This specific tactical difference allows them to achieve greater distances as they must travel the length and breadth of the field during match-play. The observed decrements in physical activity were also position specific, with defenders shown to have the highest decrements in running performance covering 6 $m \cdot min^{-1}$ less during the second half when compared to the first half. However, it is not possible to determine whether the decrement is related to fatigue or pacing strategies adapted by defenders during match-play (2). Regardless of the above, the results have practical implications for coaches on when best to make player interchanges during match-play.

The current study agrees with the previous findings of Sell and Ledesma (29) and Macutkiewicz and Sunderland (16) that reported no differences in HR_{mean} and HR_{peak} across positional lines of play within elite female hockey cohorts. However, positional differences were observed regarding time spent at different levels of intensity, Sell and Ledesma (29) suggested that the forwards spent more time at higher percentages of HR_{peak}. In contrast to the above findings our observations show that defenders spend more time >85% HR_{peak}. Our results are in agreement with Macutkiewicz and Sunderland (16) who suggested that although the forwards performed more moderate - high intensity exercise they were rewarded with more time to recover due to the roll on roll off substitution rule resulting in defenders having more time spent at higher percentages of HR_{peak}. The results of this study need to be considered within the context of the study's limitations. Firstly, with no technical data it is very difficult to assess the efficiency of players' physical activity. Additionally, although acceptable validity and accuracy was reported for the specific GPS units used within the current study, it should be noted that previous research has questioned the accuracy of GPS for the measurement of high-speed movement (10). Finally, each player is biologically different in both stature and physical capacity. With this in mind the authors advocate the development of individualised player specific running thresholds for female hockey players (4). The results of this study need to be interpreted within the context of the studies limitations. No measure of match dynamics (win or loss) and tactical styles of play were considered. Recently, studies have shown there to be match to match variation in other field sports (5,25). Future studies should report the typical match-to-match variation of GPS variables with elite female field hockey. To date no studies have examined the physical activity profiles of elite female field hockey players during a condensed high intensity period with quick turnarounds such as an international tournament environment. Therefore, we recommend that the changes in physical activity be reported for these highly demanding periods. Finally, we suggest that future research should consider the current advancements in field sports and the known energetic cost of accelerated movements. Therefore, an analysis of the metabolic power profile of elite international female hockey is warranted to improve coaches understanding of the energetic cost associated with competitive match-play.

PRACTICAL APPLICATIONS

The current study provides an insight into the physical and physiological demands of elite international female hockey across both positions and halves of play. During competitive match-play players are likely to cover 61 % of their TD > 8 $km \cdot h^{-1}$ irrespective of position. Our results showed that defenders spent more time in match-play and covered more TD when compared to other positions. Midfielders were found to cover on average 68 % of their TD distance > 8 $km \cdot h^{-1}$ which was more than defenders (9 %) and the forwards (2%). When high-speed was considered, midfielders covered over 15% of their TD > 16 $km \cdot h^{-1}$ which was similar to forwards (14 %) but significantly greater than defenders (10%). The results highlight the need for coaches to consider the positional profile of match-play prior to planning training regimen in order to best replicate players' specific match-play physical activity profile. For example, midfield players should be placed into drills that allow them to cover more HSD while forwards should be placed into more intense drills that allow them to cover more distance in a shortened period in order to increase their RTD to that similar of match-play. Previous research has shown a strong linear association between HR and volume of oxygen consumption, which can then be used to determine the level of intensity and the physiological demands in competitive match-play (6). Therefore, with the use of HR monitors the monitoring time spent at different zones and average HR can be used to effectively reflect the aerobic metabolic demands of competitive match-play (6). Our data therefore confirm that competitive match-play is mainly aerobic in nature. At set time points within a periodised plan coaches should aim to have specific periods of training drills >85 % HR_{peak}. We observed that defenders were the only position to have a notable decrement in running performance across halves of play. However, in order to reduce the likelihood of these reductions in physical activity it may be suggested that half-time nutritional strategies, in addition to a half-time re-warm up strategy be implemented by coaches. Overall the current study provides normative data on the physical activity and physiological profiles of elite international female hockey players. From these findings, it may be suggested that coaches use these data to implement position specific training drills in order to best replicate the demands of each position. Furthermore the data will aid coaches in developing specific player interchange protocols during match enviroments.

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TABLE AND FIGURE CAPTIONS

Table 1. The physical demands of elite international female field hockey across specific speed zones, as determined by GPS technology during match-play. All data is presented as mean ± SD.

a,b,c signifies the positional variation between the defenders (a), midfield (b) and forwards (c) (TD: $p \leq 0.001$, $\eta = 0.58$, Large; HSD $p \leq 0.001$, $\eta = 0.41$, Large).

Table 2. The physiological demands of elite international female field hockey across specific heart rate zones, as determined by heart rate monitors during match-play. All data is presented as mean ± SD.

* signifies the difference between the first and second halves ($p = 0.04$; $\eta^2 = 0.09$; Medium). The letter a signifies the positional variation between the defenders (a), midfield (b) and forwards (c) (Time > 85% HR_{peak} $p = 0.001$; $\eta^2 = 0.22$; Medium).

Figure 1. The relative total distance (RTD) ($m \cdot min^{-1}$) covered across all three positions during competitive match-play. All data is presented as mean ± SD.

a,b,c signifies the positional variation between the defenders (a), midfield (b) and forwards (c). The midfield and forwards were seen to cover significantly more RTD during competitive match-play ($p \leq 0.001$, $\eta = 0.58$, Large).

Figure 2. The RHSD (relative high-speed distance) m: >16 $km \cdot h^{-1}$ ($m \cdot min^{-1}$) covered across all three positions during competitive match-play. All data is presented as mean ± SD.

a,b,c signifies the positional variation between the defenders (a), midfield (b) and forwards (c) The midfield and forwards were seen to cover significantly more RHSD during competitive match-play ($p \leq 0.001$, $\eta = 0.41$, Large).

Figure 3. The time spent at different heart rate zone as a percentage of match-play across all three positions. All data is presented as mean ± SD.

A significant difference in time spent > 85% HR_{peak} (*) between the first and second halves ($p = 0.04$, $\eta = 0.09$, Small). The letters a,b,c signifies the positional variation between the defenders (a), midfield (b) and forwards (c) ($p \leq 0.001$ $\eta = 0.22$, Medium). The defenders were observed to spend significantly more time > 85% HR_{peak} across all three positions. The number 1,2,3,4 signifies the variation in time spent in specific heart rate zones. The defenders were observed to spend significantly more time in zones 1 and 2. The midfield and forwards were observed to spend significantly more time in zones 2, 3 and 4 ($p \leq 0.001$ $\eta = 0.19$, Medium).

Figure 4. The distance covered across various speed thresholds with respect to position during competitive match-play. All data is presented as mean ± SD.

a,b,c signifies the positional variation between the defenders (a), midfield (b) and forwards (c) (all $p \leq 0.001$)

Table and Figures

Table 1.

	Average	Defender	Midfield	Forward
Duration (min)	44 ± 7	50 ± 8 [b,c]	43 ± 5 [a]	41 ± 6 [a]
Total Distance (m)	5540 ± 521	5696 ± 530 [b,c]	5555 ± 456 [a]	5369 ± 578 [a]
Total Distance ($m \cdot min^{-1}$)	126 ± 23	114 ± 7 [c]	129 ± 5 [c]	131 ± 10 [a,c]
High Speed Distance ($m \cdot min^{-1}$)	13 ± 9	10 ± 2	16 ± 3	15 ± 5
Zone 1 (0-7.9 $km \cdot h^{-1}$)	1982 ± 394	2432 ± 400	1936 ± 353	1936 ± 430
Zone 2 (8-15.9 $km \cdot h^{-1}$)	2842 ± 428	2791 ± 450 [b]	2944 ± 378 [a,c]	2792 ± 456 [b]
Zone 3 (15.9-19.9 $km \cdot h^{-1}$)	587 ± 128	473 ± 110 [b]	675 ± 105 [a,c]	612 ± 170 [b]
Zone 4 (> 20 $km \cdot h^{-1}$)	125 ± 28	99 ± 23	135 ± 21	141 ± 39

Table 2.

	Average	Defender	Midfield	Forward
HR_{mean} (%)	85 ± 5	86 ± 2	87 ± 2	85 ± 12
HR_{peak} (%)	96 ± 4	95 ± 1	96 ± 5	95 ± 1
Zone 1 < 69% HR_{peak} (min)	11 ± 3	13 ± 5	10 ± 2	9 ± 3
Zone 1 < 69% HR_{peak} (%)	24 ± 5	26 ± 6 [3,4]	22 ± 3 [2,3,4]	23 ± 2 [2,3,4]
Zone 2 70-84% HR_{peak} (min)	15 ± 5	12 ± 5	14 ± 4	15 ± 3
Zone 2 70-84% HR_{peak} (%)	33 ± 4	24 ± 4	33 ± 6	37 ± 3
Zone 3 85-89% HR_{peak} (min)	18 ± 4 [*]	22 ± 4 [b,c]	17 ± 3 [a]	14 ± 4 [a]
Zone 3 85-89% HR_{peak} (%)	40 ± 3 [*]	44 ± 2 [b,c]	40 ± 4 [a]	33 ± 3 [a]
Zone 4 > 90% HR_{peak} (min)	3 ± 1	3 ± 2	3 ± 1	3 ± 1
Zone 4 > 90% HR_{peak} (%)	6 ± 1	6 ± 2 [*]	6 ± 1	7 ± 1

Figure 1.

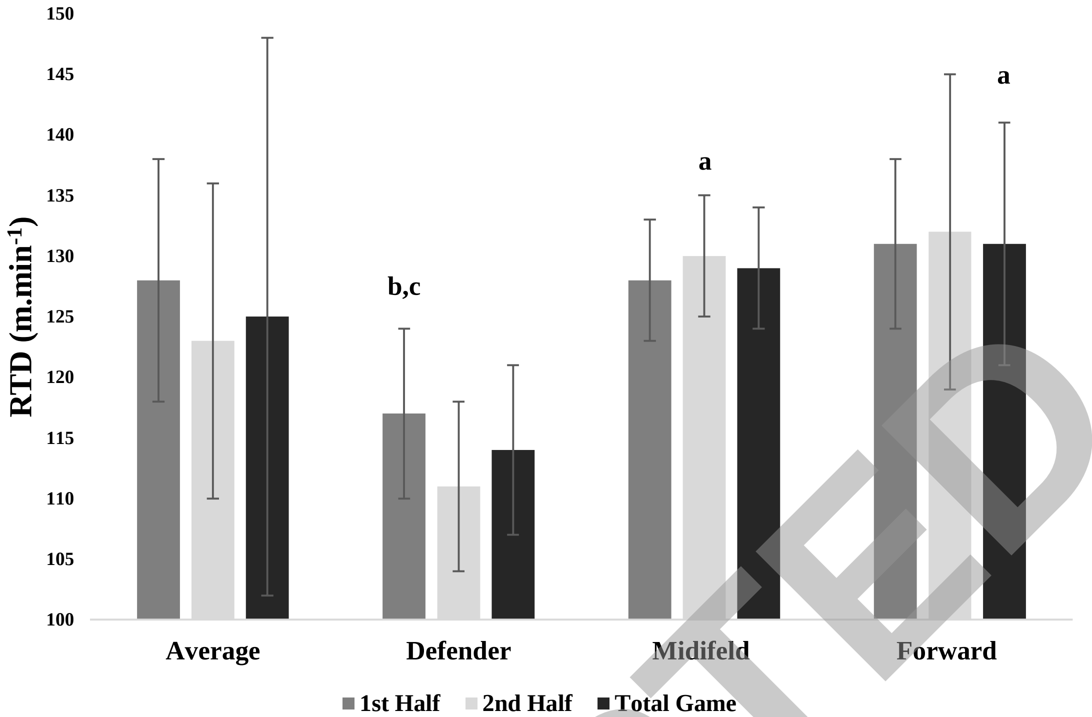

Figure 2.

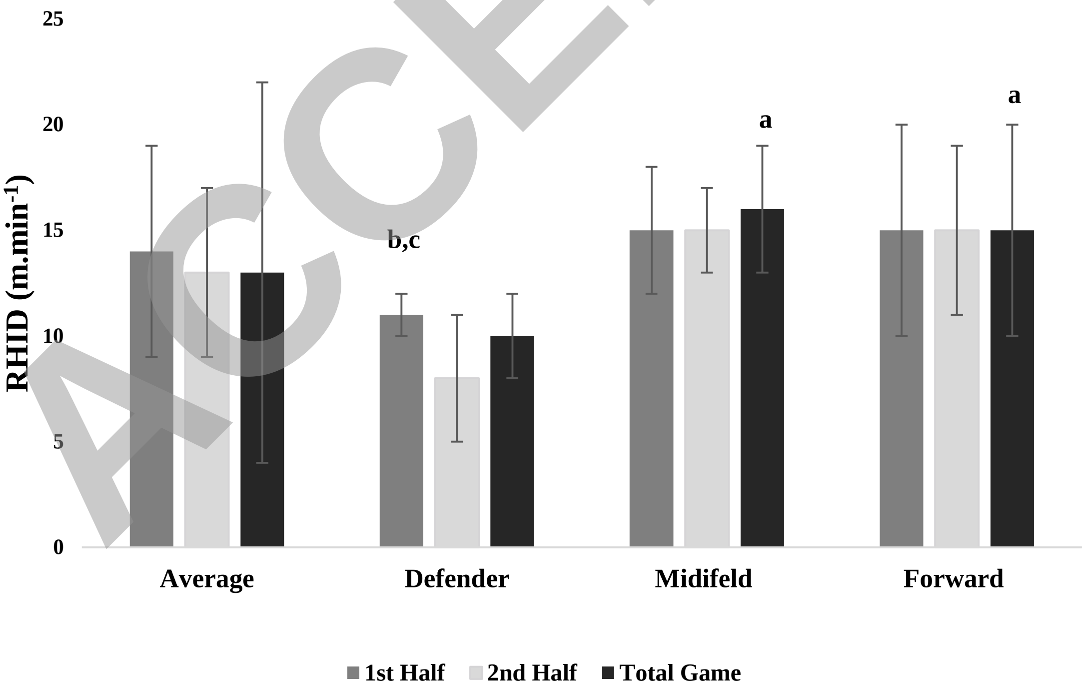

Figure 3.

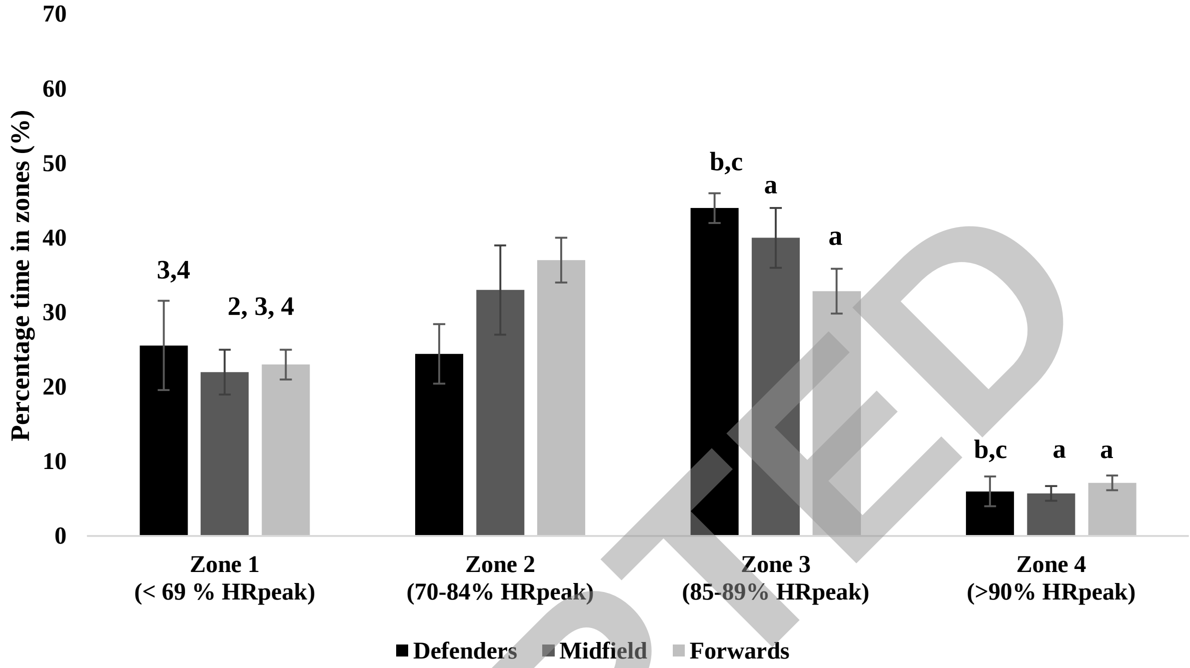

Figure 4.