Article

Investigating the Effect of Individual Rotations on the Physical and Physiological Performance in Elite Female Field Hockey Players

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Abstract: To quantify the rotational demands of elite female field hockey with respect to position. Twenty-eight ($n = 28$) elite international field hockey players were recruited during the 2018–2020 seasons. Players were monitored with GPS technology and heart-rate monitors. Methods: Activity was categorised into total distance (m), relative total distance ($\text{m} \cdot \text{min}^{-1}$), high-speed distance (m ; $16 \text{ km} \cdot \text{h}^{-1}$), relative high-speed distance ($\text{m} \cdot \text{min}^{-1}$), max velocity ($\text{km} \cdot \text{h}^{-1}$), and percentage maximal velocity ($\%V_{\text{max}}$). Physiological demands were assessed via heart rate measures (bpm and $\% \text{HR}_{\text{max}}$) and time $> 80\%$ heart rate maximum. Results: A single rotation equated to $7 \pm 0.8 \text{ min}$. Players covered a mean total distance of was $868 \pm 132 \text{ m}$ ($125.7 \pm 5.9 \text{ m} \cdot \text{min}^{-1}$) with $140 \pm 39 \text{ m}$ at high-speed ($21.7 \pm 3.6 \text{ m} \cdot \text{min}^{-1}$). A significant difference was reported for relative total ($p \leq 0.001$), and high-speed ($p \leq 0.001$), distance across positional. Forwards were reported to cover the most relative total and high-speed distance ($d = 1.0$) when compared to defenders and midfielders. Conclusion: The study provides normative data for rotational demands of elite female field hockey. Coaches should consider these demands when developing training drills to better optimise the positional physical and physiological demands of competitive match-play.

Keywords: team sport; GPS; intermittent exercise; running performance; high intensity work-rate

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1. Introduction

Field hockey can be best described as a stick and ball field-based sport comprised of both technical and tactical components that are completed at moderate to high speeds [1–3]. In recent years, field hockey has undergone vast technical and structural changes. One of these significant changes occurred in 2016 when the structure of the game went from two halves to four quarters. Match-play now consists of four 15 min quarters (Q's) with a 2 min break separating quarters 1 and 2 and quarters 3 and 4 with half-time consisting of a 10 min break separating quarters 2 and 3. However, in 1992, the International hockey federation (FIH) introduced the “rolling substitutions” rule whereby substitutions could take place at any time during the game. These are known as “rotations” by coaching and performance staff. A total of eighteen players are eligible to play during match-play: two keepers and 16 outfield players. During match-play, 11 players may be on the pitch at one time with a total of five additional players available to roll-on and roll-off at any time. Anecdotally, players will perform 6–8 rotations during a game with the timing of these rotations pre-determined based on the tactical decisions of the Head Coach.

Research focused on elite female hockey match-play has increased substantially, with these studies reporting that typically players cover on average $4847 \pm 58 \text{ m}$ ($127.6 \pm 15.3 \text{ m} \cdot \text{min}^{-1}$) with $580 \pm 147 \text{ m}$ ($15.3 \pm 3.9 \text{ m} \cdot \text{min}^{-1}$) performed above $16 \text{ km} \cdot \text{h}^{-1}$ [3–8].

McMahon and Kennedy [7] were the first to report the changes in player's activity profiles following structural changes to competitive match-play—a significant increase in relative total ($7.5 \text{ m} \cdot \text{min}^{-1}$, $d = 0.6$) and high-speed distance ($0.6 \text{ m} \cdot \text{min}^{-1}$, $d = 0.3$). Furthermore, a substantial decrease in low-speed relative distance ($-2.2 \text{ m} \cdot \text{min}^{-1}$, $d = 0.4$) during match-play was noted in conjunction with these rule changes. In recent years, McGuinness et al. (2018) observed changes in the running performance of elite female hockey players across the four quarters of match-play. Within this literature, defenders ($5181 \pm 607 \text{ m}$) were shown to cover the most total distance, meanwhile it was reported that midfielders cover the most distance at moderate intensity ($1313 \pm 173 \text{ m}$). However, no differences were reported for relative distance across quarters of play. Significant differences were observed for relative high-speed distance across quarters with a significant drop from quarter 1 to quarter 2 and further reductions between quarter 2 and quarter 4. When positions were considered, forwards were observed to cover the most relative distance at high-speed ($18.2 \pm 7.9 \text{ m} \cdot \text{min}^{-1}$) when compared to the defenders ($13.8 \pm 4.8 \text{ m} \cdot \text{min}^{-1}$) and midfielders ($14.8 \pm 6.2 \text{ m} \cdot \text{min}^{-1}$).

Due to greater interest in match demands and their influence upon match outcome, practitioners have begun to monitor duration specific moments within competitive match-play, such as rolling average and rotational running performance demands [5,6,9–12]. Previously, McGuinness et al. [6] quantified the peak running intensity of elite female field hockey players during match-play. Irrespective of position, players were reported to cover an average peak relative distance of $159\text{--}201 \text{ m} \cdot \text{min}^{-1}$. Forwards were observed to have the highest peak 1 min rolling average ($200 \pm 11 \text{ m} \cdot \text{min}^{-1}$) when compared to the defenders ($188 \pm 16 \text{ m} \cdot \text{min}^{-1}$) and midfielders ($195 \pm 15 \text{ m} \cdot \text{min}^{-1}$). Following on from these findings, Linke and Lames [11] quantified the running performance of substitutes within elite male field hockey. During each rotation, players would cover an average relative distance of $139 \text{ m} \cdot \text{min}^{-1}$, with the mean distance covered during rotation 1 ($157 \text{ m} \cdot \text{min}^{-1}$) and rotation 2 ($143 \text{ m} \cdot \text{min}^{-1}$) decreasing significantly ($p \leq 0.05$). As per current international rules, five players are available to be substituted during match-play, with coaches using these roll on and roll off interchanges as a method to maintain higher work-rates across all periods, understanding the demands of these interchanges would appear important from a performance and training replication perspective.

Due to the roll-on roll-off nature of these interchanges, coaching staff have begun to focus on the performance requirements of these rotations to best replicate and exceed these demands within training situations when appropriate. However, currently, there is a limited number of research studies that have focused on the rotational demands of elite female field hockey [5,11]. Therefore, an examination of the physical and physiological demands during each player rotation in elite female field hockey is warranted to aid coaching practice with respect to training drill creation and construction. By understanding these physical and physiological demands it will enable practitioners to create training segments that better replicate the position-specific demands of competitive match-play, allowing the coaching staff to construct duration specific small-sided games that in turn replicate the rotational demands of match-play. Given the above, the aim of the current study was to quantify the physical and physiological performance demands of elite female field hockey players with respect to rotations. Secondly, we aimed to understand these demands across the positional lines of play. It was hypothesised that forwards would have a higher relative total distance; midfielders would cover the greatest distance above $16 \text{ km} \cdot \text{h}^{-1}$ while the defenders would spend the most amount of time $> 80\%$ heart rate max (HR_{max}).

2. Materials and Methods

2.1. Experimental Approach to the Problem

The current study was observational in nature and designed to quantify the physical and physiological rotational demands of elite female hockey players using GPS technology (10-Hz, STATSports Apex Unit, STATSports Group Limited, Sonra 2.1.15, Newry, Northern

Ireland, UK) and heart rate monitors (Polar T-31, Polar Electro Oy, Kempele, Finland). Twenty-eight ($n = 28$) elite international female hockey players were observed during twenty-seven competitive matches ($n = 27$). All competitive matches that occurred during the 2018–2020 seasons were included in the data set. Overall, there were three hundred and ninety five ($n = 395$) observations included in the data set. On average, players appeared in thirteen (13 ± 8) of the twenty-seven games. Of the 27 games, 12 games were official FIH tournaments including the FIH Series Finals (5), Europeans (5) and the Olympic qualifiers (2). The rest of the games that were included in the data set were friendlies against other senior national teams that were ranked within the top 16. In order for a friendly game to be included in the data set the following criteria must be met: (1) The game must follow the official FIH format of 4 Qs and breaks in play (2); The teams may only have 18 players on the bench—16 outfield and 2 goalkeepers; (3) The umpires must be either internationally or national recognised. All participants were categorised by the head coach into three positional lines of play: defenders ($n = 8$), midfielders ($n = 9$), and forwards ($n = 11$), respectively. If a player was to play in a position that they were not previously categorised into by the head coach, this data set was removed from the cohort of data. In order to gain a better understanding of the average rotational demands, rotational data were only included in the current study if the player spent more than 90% of the team's minimum rotation duration on the field ($\sim 3:40$ min). Prior to match-day, players were advised to abstain from any strenuous activity and were advised to maintain their normal pre-match routine and diet with special emphasis being placed on the intake of fluids and carbohydrates.

2.2. Participants

Twenty-eight ($n = 28$) elite international field hockey outfield players (26 ± 3 years; 162.7 ± 12 cm; 67.3 ± 5.4 kg) were recruited to participate in the study. At the time of the current study, the team in question was ranked 8th in the FIH world rankings and players were part of the country's Tokyo 2020 Olympic training panel (9 ± 4 years at International level) and were therefore deemed the best players in the country during the observational period. Once ethical approval was granted, participants were informed of the benefits and procedures of the current study. Written informed consent and medical declaration were obtained from participants in line with the procedures set by the research ethics committee of the Technological University of Dublin (REC-PGR26-201819).

2.3. Experimental Procedures

During all competitive match-play situations, participants wore an individual GPS unit (10-Hz, STATSports Apex Unit, STATSports Group Limited, Newry, Northern Ireland, UK) to understand participants running performance across each rotation of play. The physiological performance was assessed through each participant wearing a HR monitor during match-play (Polar T-31, Polar Electro Oy, Kempele, Finland). Fifteen minutes prior to match-play each unit was switched on to allow the unit to establish a satellite connection. Each participant wore their own individual GPS unit within the confines of a vest between the shoulder blades. Prior to match-play, players' individual rotations were pre-determined by a member of the management team. It was each individual player's responsibility to ensure they rotated with the correct players marked on the sheet at the correct time. There was also a member of staff allocated to monitor the bench during competition to make sure players stayed on top of their rotation times. Once a player had finished their rotation, they were asked to take their water bottle and walk straight to the end line and back to the bench where they were asked to sit until it was time for their next rotation. If for any reason a player was unable to rotate with another player, the sports scientist would take note of this on the rotation timings sheet. Given the use of rolling substitutes, the time each participant spent in match-play was noted by the sports scientist with the use of a customised IOS app (Coaches Clock, Version 1.3.2, USA). Upon the completion of match-play, the data were downloaded using proprietary software (Apex SONRA, STATSports, Newry, Northern Ireland, UK), with all data for respective rotations

completed analysed retrospectively and applied to each individual play. All data were then exported to a bespoke database (Microsoft Excel (V15); Microsoft, Redmond, USA). Each individual rotation was then retrospectively cut using the pre-determined rotational timing sheet. The sports scientist was responsible to match up the rotational times with the movement graph on the proprietary software. If at any stage, the sports scientist was unable to determine where a rotation was made, they were encouraged to use the video footage from the match. All data were then exported to a bespoke database (Microsoft Excel(V15); Microsoft, Redmond, USA).

Participants' speed thresholds were classified based on previous zones used in elite female field hockey literature [13]. Variables of interest included time on feet (min), total distance (m), relative total distance ($\text{m} \cdot \text{min}^{-1}$), high-speed distance ($\text{m} \geq 16 \text{ km} \cdot \text{h}^{-1}$), relative high-speed distance ($\text{m} \cdot \text{min}^{-1}$), sprint distance ($\text{m} \geq 20 \text{ km} \cdot \text{h}^{-1}$), relative sprint distance ($\text{m} \cdot \text{min}^{-1}$), no. of sprints ($n; >20 \text{ km} \cdot \text{h}^{-1}$), maximal speed ($\text{km} \cdot \text{h}^{-1}$), percentage maximal speed (% V_{max}), accelerations ($n; \geq 4 \text{ m} \cdot \text{s}^{-2}$) and decelerations ($n; \leq -4 \text{ m} \cdot \text{s}^{-2}$). Physiological demands were also assessed during match-play with variables of interest including HR_{max} (bpm), HR_{max} (%), time $\geq 80\% \text{ HR}_{\text{max}}$ (min: ss). Prior to the observational period, players completed the Yo-YoIR1 to determine each participant's HR_{max} . The highest heart rate obtained by the participant during this test was deemed to be the player HR_{max} . However, if a participant obtained a higher HR_{max} throughout the course of testing, this figure would then be replaced and all data prior to this reading were then re-analysed ($n = 2$). If at any stage an athlete's heart rate data did not record, that specific rotation was omitted for analysis.

2.4. Statistical Analysis

Data are presented as a mean $\pm$ standard deviation (SD) with 95% confidence intervals (95% CIs) and partial Eta-squared (η^2) unless stated otherwise. Multiple two-way analyses of variance (ANOVAs) were used to determine the potential differences in locomotor activity and physiological variables across positional groups ($n = 3$) and for each rotation. Significance was set at $p \leq 0.05$. When significant main effects were observed, Games–Howell post-hoc test was applied. Partial Eta-squared standardised effect sizes (ES) were defined as ≤ 0.01 , small; >0.01 – 0.06 , medium; >0.06 – 0.14 , large [14]. Cohens d standardised ES were defined as ≤ 0.2 , small; >0.2 – 0.5 , medium; >0.5 – 0.8 , large, ≥ 0.8 , very large [15]. Where an effect size Cohen's d of > 0.5 (medium) was observed, it was flagged as a potential difference. All statistical analyses were performed using SPSS for Windows (Version 22, SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Physical Performance Demands across Rotations

Selected running variables are presented in Tables 1 and 2. When total distance was observed, no significant interaction was reported between position ($F(8, 1766) = 0.08$; $p = 0.9$; $\eta^2 = 0.001$; small) and rotation ($F(8, 1766) = 0.5$; $p = 0.8$; $\eta^2 = 0.002$; small). A significant interaction between position ($F(2, 541) = 9.8$; $p \leq 0.001$, $\eta^2 = 0.05$, small) and high-speed distance (m). However, when each rotation was considered, no interaction was reported ($F(8, 1766) = 2$; $p = 0.7$; $\eta^2 = 0.008$; small). When positions were considered, a significant main effect was observed. Defenders were reported to cover significantly less high-speed distance (108 ± 56) when compared to the midfield (149 ± 65 ; $d = 0.7$; large) and forwards (157 ± 73 ; $d = 0.8$; large). Forwards were also reported to cover significantly more high-speed distance than the midfield (149 ± 65 ; $d = 1.1$; large). There was significant interaction between position ($F(2, 1766) = 15$; $p \leq 0.001$; $\eta^2 = 0.02$; small) and sprint distance (m); however, when each rotation was considered, no interaction was reported ($F(8, 1766) = 0.9$; $p = 0.5$; $\eta^2 = 0.004$; small). When positions were considered, a significant main effect was observed. Defenders were reported to cover significantly less sprint distance (27 ± 8) when compared to the midfield (30 ± 10 ; $d = 0.3$; medium) and forwards (34 ± 9 ; $d = 0.8$; large). There was significant interaction between position ($F(2, 1766) = 11$;

$p \leq 0.001$; $\eta^2 = 0.01$; small) and maximal speed ($\text{km} \cdot \text{h}^{-1}$); however, when each rotation was considered, no interaction was reported ($F(8, 1766) = 1.0$; $p = 0.5$; $\eta^2 = 0.004$; small). Defenders (22.9 ± 0.5) were likely to achieve a lower maximal speed ($\text{km} \cdot \text{h}^{-1}$) when compared to the forwards (23.2 ± 0.7 ; $d = 0.5$; medium) and midfielders (23.0 ± 0.8 ; $d = 0.2$; medium). A significant interaction was observed across position ($F(2, 1766) = 0.5$; $p = 0.04$; $\eta^2 = 0.004$; small) and rotation ($F(8, 1766) = 0.8$; $p = 0.7$; $\eta^2 = 0.007$; small) for maximal speed (%). Defenders (77 ± 2) were likely to achieve a lower maximal speed (%) when compared to the forwards (79 ± 2 ; $d = 1.0$; medium) and midfielders (79 ± 2 ; $d = 1.0$; medium).

3.2. Physiological Performance Demands across Rotations

Selected physiological demands are presented in Tables 1 and 2. When HR_{max} (bpm) was observed, a significant interaction was reported between position ($F(2, 1766) = 31.0$, $p \leq 0.001$; $\eta^2 = 0.03$; small); however, no significant interaction was observed across rotations ($F(8, 1766) = 1.8$; $p = 0.07$; $\eta^2 = 0.08$; small). When positions were considered, a significant main effect was observed. Defenders were reported to have a lower HR_{max} (bpm) (183 ± 3) when compared to the midfield (188 ± 3 ; $d = 1.7$; very large) and forwards (190 ± 3 ; $d = 2.3$; very large). Forwards were also reported to achieve a higher heart rate when compared to midfield (149 ± 65 , $d = 0.6$; medium). When % HR_{max} was observed, a significant interaction was reported between position ($F(2, 1766) = 12.8$; $p \leq 0.001$; $\eta^2 = 0.01$; small). However, no significant interaction was observed across rotations ($F(8, 1766) = 0.07$; $p = 0.7$; $\eta^2 = 0.003$; small). When positions were considered a significant main effect was observed. Defenders were reported to achieve a lower HR_{max} (%) (86 ± 2) when compared to the forwards (89 ± 3 ; $d = 1.2$; large) and midfield (89 ± 3 ; $d = 1.2$; large).

Table 1. The physical and physiological demands of elite international female field hockey across rotations, as determined by GPS technology during match-play. All data are presented as mean $\pm$ SD.

		Duration (min)	Total Distance (m)	Total Distance (m·min)	High- Speed Distance	Sprint Distance	No. of Accelera- tions	No. of Decelera- tions	Peak Speed (km·h)	Max Speed (%)	No. Sprints > 20 km·h	Peak HR (bpm)	HR _{max} (%)	Time > 80% HR _{max} (min:ss)
Avg. Rotation		7:00 $\pm$ 0:50	868 $\pm$ 132	124.9 $\pm$ 10.7	140 $\pm$ 39	31 $\pm$ 13	5 $\pm$ 2	7 $\pm$ 2	23.0 $\pm$ 0.9	76 $\pm$ 1	2 $\pm$ 1	187 $\pm$ 8	86 $\pm$ 4	4:20 $\pm$ 1:30
Avg. Defender		7:30 $\pm$ 3:15	881 $\pm$ 138	119.8 $\pm$ 11.0	117 $\pm$ 34	26 $\pm$ 11	5 $\pm$ 2	7 $\pm$ 2	22.8 $\pm$ 0.8	74 $\pm$ 3	2 $\pm$ 1	189 $\pm$ 6	84 $\pm$ 4	4:18 $\pm$ 1:20
Avg. Midfield		7:20 $\pm$ 1:15	884 $\pm$ 117	123.6 $\pm$ 7.6	153 $\pm$ 30	33 $\pm$ 12	5 $\pm$ 1	8 $\pm$ 2	23.3 $\pm$ 0.9	78 $\pm$ 4	2 $\pm$ 1	188 $\pm$ 6	90 $\pm$ 6	4:20 $\pm$ 1:30
Avg. Forward		6:30 $\pm$ 2:30	836 $\pm$ 132	131.1 $\pm$ 11	160 $\pm$ 37	36 $\pm$ 15	6 $\pm$ 2	7 $\pm$ 2	23.3 $\pm$ 0.9	73 $\pm$ 3	3 $\pm$ 1	184 $\pm$ 10	86 $\pm$ 5	4:10 $\pm$ 2:10
R1	Team Avg.	6:30 $\pm$ 2:30	866 $\pm$ 141	126.7 $\pm$ 9.5	145 $\pm$ 45	31 $\pm$ 11	6 $\pm$ 2 *	8 $\pm$ 1 *	23.1 $\pm$ 0.4	78 $\pm$ 2 *	2 $\pm$ 1	188 $\pm$ 8	89 $\pm$ 5 *	4:18 $\pm$ 1:30
R2	Team Avg.	7:00 $\pm$ 2:30	855 $\pm$ 99	126.4 $\pm$ 11.9	136 $\pm$ 34	28 $\pm$ 9	5 $\pm$ 2	7 $\pm$ 2	23.0 $\pm$ 0.3	78 $\pm$ 2 *	2 $\pm$ 1	189 $\pm$ 7	89 $\pm$ 5 *	4:34 $\pm$ 1:30
R3	Team Avg.	7:00 $\pm$ 2:30	837 $\pm$ 109	124.2 $\pm$ 10.7	132 $\pm$ 42 ¹	28 $\pm$ 14	5 $\pm$ 2	7 $\pm$ 2	22.8 $\pm$ 1.6	78 $\pm$ 3 *	2 $\pm$ 1	189 $\pm$ 7	89 $\pm$ 5 *	4:21 $\pm$ 1:20
R4	Team Avg.	7:30 $\pm$ 2:55	874 $\pm$ 106	119.8 $\pm$ 10.6	131 $\pm$ 31 ¹	29 $\pm$ 11	5 $\pm$ 2	7 $\pm$ 2	23.0 $\pm$ 0.4	78 $\pm$ 3 *	2 $\pm$ 1	188 $\pm$ 8	89 $\pm$ 5	4: 23 $\pm$ 2:00
R5	Team Avg.	7:30 $\pm$ 2:55	872 $\pm$ 121	120.7 $\pm$ 11.6	129 $\pm$ 40 ¹	27 $\pm$ 11	5 $\pm$ 1	7 $\pm$ 2	22.6 $\pm$ 0.6	77 $\pm$ 3	2 $\pm$ 1	187 $\pm$ 7	88 $\pm$ 5 *	4:21 $\pm$ 1:30
R6	Team Avg.	8:00 $\pm$ 3:00	891 $\pm$ 131	118.8 $\pm$ 8.9	131 $\pm$ 41 ^{1,2}	31 $\pm$ 13	5 $\pm$ 2	7 $\pm$ 2	23.0 $\pm$ 1.2	78 $\pm$ 3 *	2 $\pm$ 1	188 $\pm$ 8	89 $\pm$ 5 *	4:39 $\pm$ 2:10
R7	Team Avg.	7:30 $\pm$ 3:20	840 $\pm$ 209	120.7 $\pm$ 9.4	135 $\pm$ 45 ¹	32 $\pm$ 19	6 $\pm$ 2 *	7 $\pm$ 2	23.0 $\pm$ 0.8	78 $\pm$ 3 *	2 $\pm$ 1	188 $\pm$ 11	88 $\pm$ 7	4:32 $\pm$ 2:10
R8	Team Avg.	7:20 $\pm$ 2:55	864 $\pm$ 61	118.8 $\pm$ 61	134 $\pm$ 36	31 $\pm$ 17	5 $\pm$ 2	7 $\pm$ 3	22.9 $\pm$ 0.7	78 $\pm$ 4 *	2 $\pm$ 1	188 $\pm$ 7	89 $\pm$ 5 *	4:26 $\pm$ 1:20

1, 2, 3, etc. signifies the positional variation between rotations. * represents the significant difference across each rotation when compared to the average rotation output.

Table 2. The physical and physiological demands of elite international female field hockey during each rotation across the positional lines of play, as determined by GPS technology during match-play. All data are presented as mean $\pm$ SD.

		Duration (min:ss)	Total Distance (m)	High-Speed Distance	Sprint Distance	No. of Ac- celerations	No. of De- celerations	Peak Speed (km·h)	Max Speed (%)	No. Sprints >20 km·h	Peak HR (bpm)	HR _{max} (%)	Time > 80% HR _{max} (min:ss)
R1	Def	7:00 $\pm$ 2:35	866 $\pm$ 108	118 $\pm$ 44 ^{b,c}	23 $\pm$ 8	5 $\pm$ 1 ^{b,c}	7 $\pm$ 2 ^{b,c}	22.5 $\pm$ 0.3 ^{b,c}	77 $\pm$ 2 ^{b,c}	2 $\pm$ 1 ^{b,c}	191 $\pm$ 4 ^{b,c}	89 $\pm$ 3	4:20 $\pm$ 1:26
	Mid	7:00 $\pm$ 2:30	832 $\pm$ 156	156 $\pm$ 37	33 $\pm$ 8	6 $\pm$ 1	8 $\pm$ 2	23.5 $\pm$ 0.5	79 $\pm$ 2	3 $\pm$ 1	186 $\pm$ 6	89 $\pm$ 6	4:13 $\pm$ 2:10
	Fwd	7:00 $\pm$ 2:30	910 $\pm$ 205	182 $\pm$ 44	44 $\pm$ 15 ^b	7 $\pm$ 2	8 $\pm$ 2	23.5 $\pm$ 0.7	79 $\pm$ 2	3 $\pm$ 1	186 $\pm$ 12	86 $\pm$ 5 ^{a,b}	4:26 $\pm$ 2:25
R2	Def	7:15 $\pm$ 2:10	828 $\pm$ 102	110 $\pm$ 25 ^{b,c}	23 $\pm$ 8 ^{b,c}	5 $\pm$ 2 ^{b,c}	7 $\pm$ 1 ^{b,c}	22.7 $\pm$ 0.6 ^{b,c}	78 $\pm$ 2	2 $\pm$ 1	192 $\pm$ 5 ^{b,c}	90 $\pm$ 4	4:33 $\pm$ 1:20
	Mid	7:15 $\pm$ 2:10	900 $\pm$ 41 ^{a,c}	155 $\pm$ 22	32 $\pm$ 67	6 $\pm$ 1	8 $\pm$ 2	23.3 $\pm$ 0.4	79 $\pm$ 3	2 $\pm$ 1	188 $\pm$ 7	90 $\pm$ 6	4:05 $\pm$ 1:25
	Fwd	7:00 $\pm$ 2:20	835 $\pm$ 116	154 $\pm$ 37	32 $\pm$ 9	5 $\pm$ 2	8 $\pm$ 2	23.0 $\pm$ 0.6	77 $\pm$ 2 ^b	3 $\pm$ 1 ^{a,b}	188 $\pm$ 11	87 $\pm$ 5 ^{a,b}	4:21 $\pm$ 2:15
R3	Def	6:55 $\pm$ 2:40	795 $\pm$ 76 ^b	99 $\pm$ 23 ^{b,c}	21 $\pm$ 7	4 $\pm$ 1 ^{b,c}	7 $\pm$ 2	22.4 $\pm$ 0.6 ^{b,c}	77 $\pm$ 2	2 $\pm$ 1	192 $\pm$ 5	90 $\pm$ 4	4:26 $\pm$ 1:15
	Mid	7:20 $\pm$ 3:00	868 $\pm$ 68	150 $\pm$ 14	31 $\pm$ 16	6 $\pm$ 2	8 $\pm$ 2 ^{a,c}	23.0 $\pm$ 1.3	78 $\pm$ 4	2 $\pm$ 1	187 $\pm$ 6	90 $\pm$ 6	4:22 $\pm$ 1:30
	Fwd	7:00 $\pm$ 0:30	858 $\pm$ 195	160 $\pm$ 62	34 $\pm$ 12	5 $\pm$ 2	7 $\pm$ 2	23.3 $\pm$ 0.8	78 $\pm$ 3	2 $\pm$ 1	188 $\pm$ 10	87 $\pm$ 5 ^{a,b}	4:26 $\pm$ 2:15
R4	Def	8:00 $\pm$ 3:15	883 $\pm$ 112	105 $\pm$ 24 ^{b,c}	23 $\pm$ 8 ^{b,c}	5 $\pm$ 1	7 $\pm$ 2	22.8 $\pm$ 0.7 ^{b,c}	78 $\pm$ 1	2 $\pm$ 1	191 $\pm$ 7 ^{b,c}	89 $\pm$ 4	4:39 $\pm$ 1:30
	Mid	7:10 $\pm$ 2:50	858 $\pm$ 98	145 $\pm$ 27	34 $\pm$ 13	5 $\pm$ 2	7 $\pm$ 2	23.2 $\pm$ 0.9	78 $\pm$ 5	2 $\pm$ 1	186 $\pm$ 6	89 $\pm$ 6	4:18 $\pm$ 2:00
	Fwd	7:10 $\pm$ 3:00	878 $\pm$ 101	156 $\pm$ 26	31 $\pm$ 11	6 $\pm$ 1 ^{a,b}	8 $\pm$ 1 ^{a,b}	23.2 $\pm$ 0.5	78 $\pm$ 3	2 $\pm$ 1	187 $\pm$ 13	86 $\pm$ 6 ^{a,b}	4:31 $\pm$ 2:15
R5	Def	7:30 $\pm$ 2:30	841 $\pm$ 127 ^b	97 $\pm$ 39 ^{b,c}	23 $\pm$ 15 ^{b,c}	4 $\pm$ 1 ^{b,c}	6 $\pm$ 3 ^{b,c}	22.2 $\pm$ 1.1 ^{b,c}	78 $\pm$ 3	2 $\pm$ 1	189 $\pm$ 6 ^{b,c}	89 $\pm$ 4	4:25 $\pm$ 1:20
	Mid	8:10 $\pm$ 2:30	910 $\pm$ 112	151 $\pm$ 18	29 $\pm$ 8	6 $\pm$ 1	8 $\pm$ 2	23.0 $\pm$ 0.5	79 $\pm$ 4 ^c	2 $\pm$ 1	186 $\pm$ 5	89 $\pm$ 5	4:21 $\pm$ 1:20
	Fwd	7:10 $\pm$ 3:00	864 $\pm$ 143	154 $\pm$ 36	33 $\pm$ 5	5 $\pm$ 1	8 $\pm$ 2	23.0 $\pm$ 0.3	77 $\pm$ 1	3 $\pm$ 1 ^{a,b}	184 $\pm$ 10	85 $\pm$ 4 ^{a,b}	4:25 $\pm$ 2:15
R6	Def	8:20 $\pm$ 3:15	890 $\pm$ 175	113 $\pm$ 46 ^{b,c}	26 $\pm$ 11 ^{b,c}	5 $\pm$ 1	8 $\pm$ 2	22.9 $\pm$ 1.1	78 $\pm$ 3	2 $\pm$ 1 ^{b,c}	192 $\pm$ 7 ^c	90 $\pm$ 5	5:18 $\pm$ 2:20 ^{b,c}
	Mid	8:10 $\pm$ 3:30	887 $\pm$ 88	146 $\pm$ 36	33 $\pm$ 18	5 $\pm$ 1	7 $\pm$ 2 ^{a,c}	23.4 $\pm$ 1.4	79 $\pm$ 4 ^c	2 $\pm$ 1	186 $\pm$ 6	89 $\pm$ 6	4:22 $\pm$ 2:00
	Fwd	7:00 $\pm$ 2:25	880 $\pm$ 103	142 $\pm$ 35	34 $\pm$ 9	6 $\pm$ 1 ^{b,c}	8 $\pm$ 1	22.8 $\pm$ 1.2	78 $\pm$ 3	3 $\pm$ 1	186 $\pm$ 10	86 $\pm$ 4 ^{a,b}	4:28 $\pm$ 2:15
R7	Def	8:25 $\pm$ 4:00	925 $\pm$ 147 ^{b,c}	115 $\pm$ 20 ^{b,c}	28 $\pm$ 12	5 $\pm$ 2 ^{b,c}	7 $\pm$ 2	22.5 $\pm$ 1.2 ^{b,c}	79 $\pm$ 3	2 $\pm$ 1	193 $\pm$ 7 ^{b,c}	90 $\pm$ 5	5:21 $\pm$ 2:00 ^{b,c}
	Mid	7:25 $\pm$ 3:10	856 $\pm$ 157	151 $\pm$ 37	34 $\pm$ 22	6 $\pm$ 2	7 $\pm$ 3	23.2 $\pm$ 1.1	80 $\pm$ 4 ^c	3 $\pm$ 1	186 $\pm$ 14	89 $\pm$ 9	4:18 $\pm$ 2:10
	Fwd	6:25 $\pm$ 3:15	808 $\pm$ 100	147 $\pm$ 69	35 $\pm$ 24	6 $\pm$ 1	7 $\pm$ 1	23.3 $\pm$ 1.3	76 $\pm$ 4	3 $\pm$ 1	184 $\pm$ 10	85 $\pm$ 5 ^{a,b}	4:15 $\pm$ 2:10
R8	Def	8:00 $\pm$ 1:00	870 $\pm$ 218	111 $\pm$ 27 ^{b,c}	24 $\pm$ 19 ^{b,c}	5 $\pm$ 2	7 $\pm$ 3 ^{b,c}	22.9 $\pm$ 0.4	77 $\pm$ 4 ^{b,c}	2 $\pm$ 1	193 $\pm$ 4 ^{b,c}	91 $\pm$ 3	4:38 $\pm$ 1:00
	Mid	7:10 $\pm$ 3:25	732 $\pm$ 269 ^a	129 $\pm$ 31	32 $\pm$ 13	5 $\pm$ 2	6 $\pm$ 4	22.9 $\pm$ 0.4	80 $\pm$ 4	2 $\pm$ 1	187 $\pm$ 5	90 $\pm$ 6	4:18 $\pm$ 1:30
	Fwd	7:30 $\pm$ 3:10	8698 $\pm$ 105 ^b	160 $\pm$ 19	38 $\pm$ 15	6 $\pm$ 3 ^{b,c}	8 $\pm$ 2	22.9 $\pm$ 0.4	78 $\pm$ 3	3 $\pm$ 1 ^{a,b}	184 $\pm$ 11	85 $\pm$ 5 ^{a,b}	4:29 $\pm$ 2:15

a, b, c signifies the positional variation between the defenders (a), midfield (b) and forwards. * represents the significant difference across each rotation when compared to the average rotation output.

4. Discussion

The primary aim of the current observational study was to quantify each rotation running performance and heart rate responses in elite female field hockey players. Secondly, we aimed to quantify the demands of individual rotations across the positional lines of play. Research conducted on elite female field hockey rotational demands is limited [5,11]. Therefore, an examination of the physical and physiological demands during each rotation in elite female field hockey is warranted. The main findings of the current study were that irrespective of position small to large effects were observed for relative total distance during each rotation when compared to average match-play outputs for elite female hockey players, with no significant difference reported across relative high-speed and relative sprint distance. Furthermore, while no difference was reported across the rotations, a significant main effect was seen across the positional lines of play for multiple GPS variables. Finally, it was observed that HR_{max} (%) was significantly different for players across the rotational phases of play.

The data reported within the current study show that regardless of position elite female field hockey players cover a total distance of 868 ± 132 m (124.9 ± 10.7 m·min⁻¹) with 140 ± 39 m (20.1 ± 4.5 m·min⁻¹) covered at high-speed across each rotation. When positional lines of play were considered a significant small to moderate difference for relative values of total distance, high-speed distance and sprint distance were observed. Specifically, defenders were reported to have the lowest relative total distance (119.8 ± 11.0 m·min⁻¹) when compared to midfield (123.6 ± 7.6 m·min⁻¹) and the forwards (131.1 ± 11 m·min⁻¹), with these differences small to very large depending on specific positional comparisons (Figure 1). Furthermore, when high-speed running was considered, very large differences were reported across positions with forwards (23.5 ± 1.2 m·min⁻¹) shown to cover increased high-speed running when compared to midfielders (21.8 ± 1.4 m·min⁻¹) and defenders (14.9 ± 1.2 m·min⁻¹), respectively (Figure 2). These findings represent a continuation of trends recently reported by McGuinness et al. [3] with respect to quarters of competitive match-play and agree with this literature. It was suggested that during the quarters of competitive match-play elite female field hockey players would cover an average relative distance of 126 ± 15.3 m·min⁻¹. Although these results were similar to that recently reported for the average quarter demands, it is important to note that all rotations have been pooled together to give an average rotational demand. Prior to match-play, coaching staff will determine their tactical approach to the opposition. Once this has been agreed, they will often implement specific match strategies such as key playing personnel being on the pitch longer than others. Coaching staff should aim to establish the average rotational demands for each individual during match-play. By knowing these individual averages, practitioners can modify duration and player numbers within small-sided games to best replicate and exceed the positional and individuals match-play demands [16].

Irrespective of positions, elite female field hockey players complete on average eight rotations during competitive match-play. During these individual rotations, players are likely to spend a mean time of 7 ± 1 min on their feet. Within these 7 min, players are likely to cover an average relative total distance of 124.9 ± 10.7 m·min⁻¹ with a relative high-speed distance of 20.7 ± 5.8 m·min⁻¹. When each rotation was considered, a significant main effect was observed for relative total distance ($p \leq 0.001$; $\eta^2 = 0.04$; medium), relative high-speed distance ($p \leq 0.001$; $\eta^2 = 0.03$; medium), and the number of sprints ($p \leq 0.04$; $\eta^2 = 0.01$; small). A significant decrease was reported for relative total distance for R1 and R2 when compared to other rotations completed by players during match-play (Figure 1). Similar to relative total distance, when relative high-speed distance was quantified, a significant decrease was reported when R1 was compared to other rotations during match-play (Figure 2). Our findings are similar to data previously reported in other team sports [17,18]. Previously, Black and colleagues [18] reported that rotation duration influenced the physical activity profile of female Australian football players within the subsequent quarter of play, specifically short (4–6 min) and moderate (7–12 min) duration rotations were shown to generate the highest activity profile during

match-play. During each rotation, forwards maintained the highest relative output when compared to the defenders and midfielders. It is possible that prior knowledge of the team's rotations strategy may be associated with these higher relative outputs. Indeed, forwards typically are required to perform a rotation of 4–9 min, depending on the tactical requirements of the coaching staff, while defenders and midfield players usually complete longer duration rotations (5–11 min) during match-play. Schimpchen et al. [19] recently reported that football player's physical output can be more critically impacted by periods of peak high-velocity running. Our results have shown that after R2 no further reduction in locomotor parameters between rotations was reported. It is apparent that after R2 regardless of position, players relative locomotor activity plateaus. Due to their nomadic nature and the speed of the game, it is likely that an element of fatigue or differential positional pacing strategies may be apparent in particular positional lines of play within elite female field hockey [19,20]. Given the extent of the reduction in physical performance across the rotations, it is suggested that, during training, coaching staff implement these typical work periods within conditioning drills to replicate and exceed match demands when required.

Figure 1. The average relative total distance $\text{m}\cdot\text{min}^{-1}$ of elite female field hockey players across each rotational period during competitive match-play. The letters a, b, c signify the positional variation between the defenders (a), midfield (b) and forwards, while 1, 2, 3, 4, 5, 6, 7, 8 represent the significant difference across each rotation when compared to each other.

Time on feet resulted in players achieving a higher percentage of HR_{max} and time above 80% HR_{max} during competitive match-play. Players attained a mean HR_{max} of 187 ± 8 bpm equating to $86 \pm 4\%$ of HR_{max} . Regardless of positional group, players were reported to spend 4.29 ± 1.4 min of the 7.0 ± 0.8 min above 80% HR_{max} . Midfielders ($90 \pm 6\%$) were reported to reach a higher percentage mean HR_{max} during each rotation when compared to the defenders ($90 \pm 6\%$) and forwards ($86 \pm 4\%$) (Figure 3). Furthermore, our study reported that midfielders spent more time above 80% HR_{max} (4.39 ± 1.5 min) when compared to the defenders (3.54 ± 1.4 min) and forwards (4.10 ± 2.1 min). These results are in line with the findings reported by Harry and Booyesen [4], who suggested that players who had a quicker heart rate recovery time had an enhanced ability to cope with the intensity of competitive match-play and could maintain the capacity to run at higher speeds. Forwards were likely to spend the least amount of time on feet during each rotation, had an overall lower mean percentage of HR_{max} , and could run at a higher intensity. These results suggest that reducing the time midfielders spend in each rotation may, in turn, increase their overall levels of intensity during match-play. Given the above,

coaches need to develop specific rotational strategies to get the most out of each individual across all the positional lines of play. By implementing such strategies, coaches can aim to reduce the accumulated fatigue that occurs due to the longer duration bouts, and in turn, minimize the effect on each individual's running performance [21,22].

Figure 2. The average relative high-speed distance $\text{m} \cdot \text{min}^{-1}$ of elite female field hockey players across each rotational period during competitive match-play. The letters a, b, c signify the positional variation between the defenders (a), midfield (b) and forwards, while 1, 2, 3, 4, 5, 6, 7, 8 represent the significant difference across each rotation when compared to each other.

Figure 3. The average time spent $> 80\%$ HR_{max} (min) of elite female field hockey players across each rotational period during competitive match-play. The letters a, b, c signify the positional variation between the defenders (a), midfield (b) and forwards.

The differences observed in the physical and physiological performance profiles of elite female hockey players across rotations highlight the potential benefits to coaching staff of knowing these demands of play. Through understanding these rotational demands,

coaches can better implement rotational and position-specific training drills. Indeed, coaches can manipulate specific drill variables to best target specific physical, technical, tactical, and physiological outcomes that may best replicate competition demand. The results of the investigation need to be interpreted within the context of several limitations. Firstly, although the study included twenty games, the investigation was completed on one elite hockey team, as such, this should be viewed as an applied case study of field hockey rotational demands for the team in question. We, therefore, recommend that practitioners utilise the methodology of the current study to create their team's rotational normative data. Secondly, as we failed to appreciate or understand the analysed team's tactical approach to each game, alongside the standard of opposition faced, these findings could be considered as contextual factors that may impact running performance. We recommend that future research is also focused on understanding how a team's tactical approach and opposition impact the running performance of players during each rotation of play. Finally, given that each players' biological profiles differ in both stature and physical capacity, it is important for authors to acknowledge the application of non-individualised speed thresholds within our analysis. As such, the authors advocate the development of individualised player-specific running thresholds for elite female hockey [23]. Finally, future research should consider the current advancements in the understanding of team sport activity profiles and the known importance of accelerations and decelerations [24]. Understanding of the acceleration and deceleration demands within elite female hockey is limited, alongside an appreciation of the metabolic power profile of competitive match-play. This added information would aid in determining our comprehension of the energetic cost associated with competitive match-play.

5. Conclusions

The current study is the first to report the physical and physiological rotational demands of elite female field hockey players with respect to positional lines of play. The mean rotation duration equated to 7 ± 0.8 min. During this time, players covered an average distance of 868 ± 132 m reflective of 124.9 ± 10.7 m·min⁻¹ of which 140 ± 39 m or 20.1 ± 4.5 m·min⁻¹ was completed at high speed. Relative distance and relative high-speed distance decrease significantly across competitive match-play. Defenders were reported to cover the least amount of relative total (115.9 m·min⁻¹) and high-speed (14.9 m·min⁻¹) distance during each rotation. Forwards were reported to cover the most high-speed running (160 ± 37 m) when compared to the midfield (153 ± 30 m) and defenders (117 ± 34 m). Although respective high-speed distances were similar, relative distances were significantly higher. We observed reductions in match-play running across rotations with respect to relative distance, with this being highest between R4 and R5. These rotations were typically observed to occur before and after half time. Practitioners should be aware of this observed drop off in running performance either side of half time and may consider implementing specific performance, nutritional or re-warm up strategies to try and limit the decrease in performance [25,26].

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Informed Consent Statement: Informed consent was obtained for this research.

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