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Research article

The Physical and Physiological Match-Play Locomotor Activity Profiles of Elite Domestic Male Field Hockey

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Abstract

A new four-quarter match format in field hockey has meant that the locomotor activity profiles of the sport are inconsistent with the literature. The aim of this investigation was to identify the physical and physiological demands of national-level male hockey players. Thirty-two male players participated in the study. Participants were monitored with GPS and heart rate monitors. Variables analysed were total time, total distance (m), relative total distance ($m.min^{-1}$), total distance in velocity bands (m), and activity intensity ($m.min^{-1}$). Mean and maximum heart rate were calculated as well as total time and percentage time spent in heart rate zones relative to HR_{max}. Players spent 52 ± 11 min in play. The total distance covered was 5986 ± 1105 m (116 ± 12 $m.min^{-1}$) with 21.4 ± 6.8 $m.min^{-1}$ of high intensity activity. Defenders covered the lowest relative total distance ($p < 0.001$) and attackers the highest ($p < 0.001$). Relative total distance in Q4 was 5% lower than in Q1and Q2 ($p < 0.05$) with moderate intensity exercise (8.1 - 15.5 $km.h^{-1}$) being 11% lower in Q4 compared to Q1 and Q2. The mean HR and HR_{max} of players were 167 ± 10 and 194 ± 11 bpm respectively. Players had a lower mean HR in Q3 (164bpm) and Q4 (164bpm) compared to Q1 (169bpm) and Q2 (168bpm; $p < 0.001$). The current study provides novel data outlining the physical and physiological activity profiles of national-level male field hockey players across playing positions as well as quarters of play. The results highlight a need to consider positional differences when implementing a training programme for players at national level.

Key words: GPS, Field Hockey, Team Sports, Heart Rate

Introduction

It is well established that field hockey is a sport characterised by a high-intensity intermittent activity profile (Ihsan et al., 2021; James et al., 2021; Kusnanik et al., 2018; Macutkiewicz and Sunderland, 2011; McGuinness et al., 2019b). However, recent rule modifications have caused several changes to the overall locomotor activity profiles of match-play (Ihsan et al., 2021). In 2014, the total game time for international field hockey was reduced from 70 minutes to 60 minutes, and the game format changed from two 35-minute halves to four 15-minute quarters (International Hockey Federation, 2019). Research has indicated that these rules have resulted in increases in the relative total distance (RTD) covered by players, with a 3.3% increase for midfielders and a 9.8% increase for forwards, and high speed running with a 7.7% difference for midfielders (McMahon and Kennedy, 2019). In 2019, England Hockey introduced the four-quarter format to the English Hockey League (EHL), but only at the elite domestic level (England Hockey, 2019). Unlike the international game, the quarters at elite domestic level, are 17.5 minutes as opposed to 15 minutes, meaning that total match time remains at 70 minutes. To account for this difference, time is not paused for penalty corners (PCs) or goals at elite domestic level. It is possible that these rule changes have altered the overall locomotor activity profiles of hockey players at elite domestic level compared to international competition.

Identifying the physical activity profiles of match-play at elite domestic level could be beneficial to coaches and support staff, as this can be used to inform training programmes, nutritional requirements, and match tactics (i.e., substitutions) (Polglaze et al., 2018). Like many team sports, wearable devices that include Global Positioning Systems (GPS) and Inertial Measurement Units (IMU) have become the predominant method of assessing the physical activity profiles associated with field hockey (Ihsan et al., 2021; James et al., 2021; Kusnanik et al., 2018; McGuinness et al., 2019b). These devices provide objective data on the quantity and intensity of exercise, with measures such as distance travelled, velocities, accelerations, and changes of direction. Whilst several studies have used GPS and IMU devices to investigate international match-play with the new rules (Ihsan et al., 2021; McGuinness et al., 2019a; McMahon and Kennedy, 2019; Morencos et al., 2017), the physiological and locomotor activity profiles remain unclear, particularly for national level players. Ihsan et al. (2021) and Morencos et al. (2017) found a progressive decline in total distance (TD) performed by elite male players in each of the four quarters, with Ihsan et al. (2021) suggesting that this was due to a decline in low-intensity distance covered (≤ 15 $km.h^{-1}$) as opposed to the high-intensity distance covered (≥ 15 $km.h^{-1}$). In contrast, McGuinness et al. (2019b) reported a decrease in high-intensity distance covered (> 16 $km.h^{-1}$) and an increase in the distance covered at a moderate intensity (8 - 15.9 $km.h^{-1}$) over the four quarters in elite female hockey players. These discrepancies could indicate a difference between the men's and women's game, or could be due to a difference in the definitions of intensity with Ihsan et al. (2021) defining high-intensity distance as ≥ 15 $km.h^{-1}$ and McGuinness et al. (2019b) defining it as > 16 $km.h^{-1}$. This highlights the need for further research on the locomotor activity profiles of the hockey to better understand the modern rule changes.

Heart rate (HR) is another objective measure that has been used to indicate the physiological activity profiles experienced by hockey players during a match (Perrotta et al., 2017). Before the rule change, Buglione et al. (2013)

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demonstrated that elite and sub-elite male hockey players had a mean HR of 84.5 ± 3.7 % and 85.8 ± 2.8 % of HR_{max} respectively, with a decline in HR in the second half compared to the first. It was identified that elite male players spent 61% of a match above 85 % HR_{max} and sub-elite 62 %. Elite international female hockey players have been found to spend 53 ± 13 % of a match above 85 % HR_{max} with the new four quarter format (McGuinness et al., 2019a). McGuinness et al. (2019b) also observed that time spent at > 70 % max HR decreased significantly across quarters. Prior to the rule change, there were no differences in HR measures in female players during a hockey match between the different playing positions (Sell and Ledesma, 2016). However, McGuinness et al. (2019a), who's study was conducted after the rule change, found that international female midfielders experience a higher HR_{peak} than forwards but not defenders, and defenders spend the highest percentage of match play above 85 % HR_{max}. This further highlights the change the new rules may have made to the game and physiological activity profiles of players. To our knowledge, no research has documented the HR of male hockey players over the new four quarter format of field hockey.

Understanding the physiological and physical locomotor activity profiles of match play provides useful information on physiological responses which could better inform training prescription and recovery strategies (Bourdon et al., 2017; James et al., 2021). Therefore, the aim of this study was to report the physical and physiological locomotor activity profiles of male field hockey players in the National League of the England Hockey League (EHL), under the new four-quarter match format. The null hypothesis is that there will be no difference in locomotor activity and physiological responses between the 4 quarters of the match.

Methods

Participants

Thirty-two male outfield hockey players (age 26.3 ± 3.1 years, stature 178.4 ± 6.2 cm, body mass 75.2 ± 7.1 kg) from two national league field hockey teams participated in the study. They consisted of nine defenders, twelve midfielders and eleven attackers. Players were monitored over ten competitive matches during the 2019/2020 season of the England Hockey League. Game data was only included if players performed in each of the four quarters of the match for a minimum of seven minutes per quarter equating to half of a quarter. 3 data sets were removed as a result. Players were informed about all testing procedures and written informed consent was obtained from all participants. Ethical approval for the study was gained from the School of Human and Health Sciences Research Ethics Panel at The University of Huddersfield

Experimental procedures

Kinematic measures

The physical activity of each participant was attained using a 10 Hz GPS unit (Optimeye S5, Catapult Sports, Melbourne, Australia). The GPS unit was encased in a custom-made vest provided by the manufacturer with the unit sitting in between the shoulder blades in the upper thoracic spine region ensuring there was no restriction to the movement of the arms or torso. Players were assigned the same GPS unit for each match to eliminate any potential inter-unit reliability error (Malone et al., 2017). The units were turned on 30 minutes prior to warm-up to allow for satellite connection. The average number of satellites and horizontal dilution of position across the entire data collection were 12.0 ± 0.3 and 0.75 ± 0.01, respectively, therefore GPS quality was considered ideal (Malone et al., 2017). Catapult S5 GPS units have previously shown acceptable levels of reliability and validity for velocity-based variables (Hoppe et al., 2018). Following each match, data files were downloaded using the GPS units using the manufacturers software (Openfield, version 1.14, Catapult Sports, Melbourne, Australia). Data was then exported to Microsoft Excel (Microsoft, Redmond, USA) for further analysis. In total there were 100 player data files (37 ATT, 38 MID, and 25 DEF).

The variables analysed across match quarters and playing positions were: Total time played (TT), total distance (TD) (m), relative total distance (RTD) ($m.min^{-1}$), total distance in velocity bands (m) and activity intensity ($m.min^{-1}$). Thresholds for the velocity zones were established using previous research (Buglione et al., 2013; Casamichana et al., 2018; Dwyer and Gabbett, 2012; Lythe and Kilding, 2011; Morencos et al., 2017; White and MacFarlane, 2013) and were categorised as follows: band 1 - Standing (< 0.2 $km.h^{-1}$), band 2 - Walking (0.2 - 8.0 $km.h^{-1}$), band 3 - Jogging (8.1 - 15.5 $km.h^{-1}$), band 4 - Running (15.6 - 23.0 $km.h^{-1}$), band 5 - Sprinting (> 23.0 $km.h^{-1}$). Using these bands, activity intensity was calculated as total distance per band/total match minutes played with bands 1 and 2 relating to low intensity activity (LIA), band 3 being moderate intensity activity (MIA) and bands 4 and 5 high intensity activity (HIA).

Physiological measures

To assess physiological activity profiles of the players, a (HR) monitor (Polar Electro, Oy, Finland) was worn around the heart line and wirelessly paired with the same players' GPS unit. HR was tracked over the course of a season, both in training and match-play to ensure the correct value was used, and HRmax was determined as the maximum heart rate achieved during the season. Values were calculated as a percentage of this figure and grouped based on previous research (Buglione et al., 2013; Lythe and Kilding, 2011; McGuinness et al., 2019a; 2019b) as follows: Band 1 - moderate intensity (65 % - 75 %), band 2 - high intensity (75 % - 85 %), band 3 - very high intensity (85 % - 95 %), band 4 - maximal intensity (>95 %). HR was also calculated per band as a percentage of total time ((total time in band/total match time played) *100).

Statistical analysis

Data are presented as mean ± standard deviation (SD). Statistical analyses were conducted using SPSS for windows (Version 26, SPSS Inc. Chicago, USA). A one-way analysis of variance (ANOVA) was used to outline any potential differences in running performance or HR across positions (attack (ATT), midfield (MID), defence (DEF)) and a repeated measures ANOVA was used to assess differences in quarters (Q1, Q2, Q3, Q4). The level of significance was set at $p < 0.05$. When significant main effects were observed a post-hoc Tukey test was applied to identify the location of the differences. Cohen's effect size (d) was paired with significance to determine the magnitude of any changes found (Sunderland and Edwards, 2017); where < 0.2 = trivial effect, 0.2 - 0.49 = small effect, 0.5 - 0.8 = moderate effect, and > 0.8 = large effect (Cohen, 1992).

Results

The running activity profiles are shown in Table 1. The mean total distance (TD) covered during matches was 5986 ± 1105 m with a mean total playing time of 52 ± 11 min. This resulted in a mean RTD of 116 ± 12 $m.min^{-1}$. On average, players covered 2246 ± 590 m walking, 2660 ± 552 m jogging, 979 ± 272 m running, and 90 ± 56 m sprinting: equating to 42.9 ± 4.0 $m.min^{-1}$ low intensity activity, 52.1 ± 9.1 $m.min^{-1}$ moderate intensity activity, and 21.4 ± 6.8 $m.min^{-1}$ high intensity activity. The TD covered in each velocity band by playing position can be seen in Figure 1. ATT covered the most running distance compared to the other positions (band 4; P = 0.001, ES 0.37). ATT had a higher sprinting distance than DEF (band 5; P = 0.18, ES 0.28).

Although no significant difference was found in TD between playing positions, a main effect was found in RTD (P = <0.001). DEF were observed to cover the lowest RTD (105 ± 13 $m.min^{-1}$) when compared to both ATT (120 ± 10 $m.min^{-1}$; P < 0.001, ES = 0.26) and MID (120 ± 9 $m.min^{-1}$; P < 0.001, ES = 0.26). ATT covered significantly more running distance (1104 ± 261 m) in comparison to the other two positions (MID = 930 ± 157 m, P = 0.011, ES = 0.82; DEF = 865 ± 361 m, P = 0.002, ES = 0.79) and significantly more sprinting distance than DEF (ATT = 109 ± 62, DEF = 70 ± 56 m; P = 0.18, ES = 0.65). Furthermore, high intensity activity revealed differences between all three positions with ATT having the highest work rate (24.8 ± 6.0 $m.min^{-1}$) and DEF the lowest (21.4 ± 6.8 $m.min^{-1}$; P < 0.001, ES = 0.27).

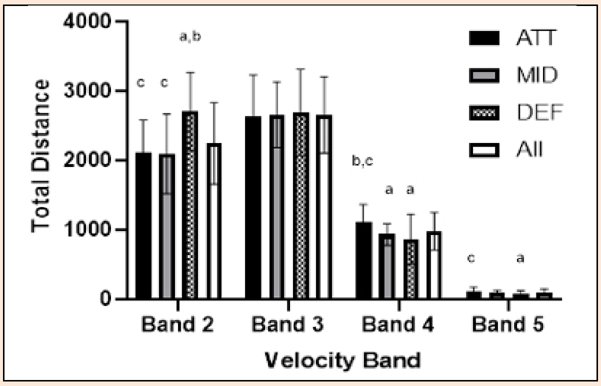

Figure 1. Total running distance in band 2 – Walking (0.2 - 8.0 km.h-1), band 3 – jogging (8.1 - 15.5 km.h-1), band 4 – running (15.6 - 23.0 km.h-1), band 5 – sprinting (> 23.0 km.h-1). [a] = significantly different to attackers (p < 0.05), [b] = significantly different to midfielders (p < 0.05), [c] = significantly different to defenders (p < 0.05)

Table 2. shows the locomotor activity profiles of players across the four quarters of a field hockey match. Total distance again showed no significant difference however there was a main effect with RTD between quarters. Q4 (113.5 ± 14.5 $m.min^{-1}$) was significantly lower when compared to Q1 (119.8 ± 17.4 $m.min^{-1}$; P = 0.022, ES = 0.4) and Q2 (119.2 ± 15.7 $m.min^{-1}$; P = 0.048, ES = 0.38) as shown in Figure 2. When activity intensity was considered, a significant main effect was observed in moderate intensity activity. MIA in Q4 (49.0 ± 15.6 $m.min^{-1}$) was significantly lower than in Q1 (55.6 ± 12.0 $m.min^{-1}$; P = 0.003, ES = 0.48) and Q2 (55.1 ± 15.5 $m.min^{-1}$; P = 0.009, ES = 0.39). There was no main effect found in LIA or HIA between the quarters.

Table 1. Mean ± standard deviation for the movement demands of sub-elite male hockey players across playing positions.

Running metric	Playing Positions			All
	Attackers	Midfielders	Defenders	
Total time (min)	50 ± 10	49 ± 10	61 ± 11	52 ± 11
Total Distance (m)	5977 ± 1158	5772 ± 947	6346 ± 1208	5986 ± 1105
Relative Total Distance ($m.min^{-1}$)	120 ± 10^{c}	120 ± 9^{c}	$105 \pm 13^{a,b}$	116 ± 12
LIA (0-8km.h^{-1}) ($m.min^{-1}$)	42.3 ± 3.3	42.5 ± 4.6	44.5 ± 3.7	42.9 ± 4.0
MIA (8.1-15.5 km.h^{-1}) ($m.min^{-1}$)	53.1 ± 7.0^{c}	55.5 ± 8.2^{c}	$45.0 \pm 9.7^{a,b}$	52.1 ± 9.1
HIA (> 15.6 km.h^{-1}) ($m.min^{-1}$)	$24.8 \pm 6.0^{b,c}$	$21.6 \pm 5.1^{a,c}$	$15.6 \pm 6.7^{b,c}$	21.4 ± 6.8

[a] = significantly different to attackers (p < 0.05), [b] = significantly different to midfielders (p < 0.05), [c] = significantly different to defenders (p < 0.05)

Table 2. Mean ± standard deviation for the movement demands of sub-elite male hockey players across playing positions and match quarters.

Movement demands	Match Quarter			
	Q1	Q2	Q3	Q4
Total time (min)	13 ± 4	13 ± 3	13 ± 4	13 ± 4
Band 2 Distance (0.2 – 8.0 km.h^{-1}) (m)	1082 ± 191	1046 ± 171	1014 ± 196	1044 ± 202
Band 3 Distance (8.1 – 15.5 km.h^{-1}) (m)	$714 \pm 195^{*,\#}$	687 ± 195	$638 \pm 191^{\wedge}$	$631 \pm 219^{\wedge}$
Band 4 Distance (15.6 – 23.0 km.h^{-1}) (m)	254 ± 98	239 ± 81	234 ± 88	253 ± 107
Band 5 Distance (> 23.0 km.h^{-1}) (m)	22 ± 20	20 ± 19	20 ± 21	28 ± 33
LIA (0-8km.h^{-1}) ($m.min^{-1}$)	42.3 ± 8.4	44.6 ± 11.8	43.8 ± 6.8	43.7 ± 9.8
MIA (8.1-15.5 km.h^{-1}) ($m.min^{-1}$)	$55.6 \pm 12.0^{+}$	$55.1 \pm 15.5^{+}$	50.9 ± 9.8	$49.0 \pm 15.6^{\wedge,\#}$
HIA (> 15.6 km.h^{-1}) ($m.min^{-1}$)	22.1 ± 8.8	21.0 ± 7.5	21.2 ± 9.0	22.2 ± 8.9

^ = significantly different to Q1 (p < 0.05), # = significantly different to Q2 (p < 0.05), * = significantly different to Q3 (p < 0.05), + = significantly different to Q4 (p < 0.05)

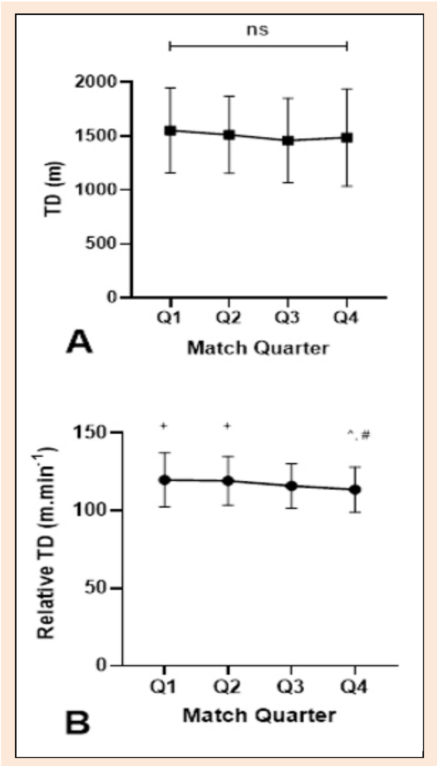

Figure 2. Distance performed over four playing quarters (Q1 - Q4) by male field hockey players. A) Total distance (m) over Q1 - Q4. B) Relative total distance (m.min-1) over Q1 - Q4. ^ = significantly different to Q1 ($p < .022$), # = significantly different to Q2 ($p < .048$), + = significantly different to Q4 ($p < .05$).

The physiological profiles are shown in Table 3. Mean HR and HR_{max}, regardless of playing position, were 167 ± 10 and 194 ± 11 bpm, respectively. Players spent an average of 60 ± 18 % of playing time at > 85 % HR_{max}. There were positional differences found during match play. EF (55.1 ± 15.5 min) were observed to spend significantly more time in the high intensity HR band throughout a match than both ATT (12 ± 6 min; P = 0.001, ES = 0.86) and MID (13 ± 4; P = 0.008, ES = 0.82).

The HR data for the players separated by HR band and match quarter is shown in Table 4. Average HR and HR_{max} data are shown Figure 3. Average HR ($P < 0.001$, ES = 0.51) and HR_{max} ($P = 0.01$, ES = 0.3) were shown to have significant main effects across the quarters. A post-hoc analysis revealed that in Q3 (164 ± 11 bpm) and Q4 (164 ± 11 bpm) players had a lower average HR than in both Q1 (169 ± 11 bpm) and Q2 (168 ± 11 bpm). When time spent in HR bands was measured, a main effect was observed across quarters in all bands. Time in HR band 2 was significantly lower ($P = 0.001$, ES = 0.5) in Q1 (3 ± 2 min) and Q2 (3 ± 2 min) compared to Q3 (4 ± 2 min) and Q4 (4 ± 2 min) and time in HR band 3 (85 – 95 % HR_{max}) was lower in Q3 (6 ± 3 min) when compared to Q1 (7 ± 3 min; P = .042, ES = 0.61) and Q2 (7 ± 3 min; P = 0.038, ES = 0.6).

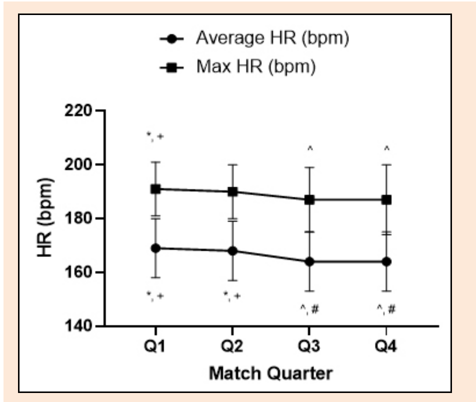

Figure 3. Average HR and max HR data for all playing positions across four quarters (Q1-Q4) of a field hockey match. ^ = significantly different to Q1 ($p < 0.05$), # = significantly different to Q2 ($p < 0.05$), * = significantly different to Q3 ($p < 0.05$), + = significantly different to Q4 ($p < 0.05$).

Discussion

The aim of this study was to assess the match-play locomotor activity profiles of elite domestic male hockey players in the English National League with reference to playing position and the new four quarter match format. The main findings are that players perform more RTD in Q1 and Q2 compared to Q4, and MIA is lower in Q4 compared to Q1 and Q2. Furthermore, average HR and HR_{max} both decreased from Q1 to Q4 for all players. To our knowledge, this is the first study to report the locomotor activity profiles of field hockey under the new English National League format and the first to report HR data for male hockey players since the introduction of the four-quarter structure. This information could be useful for coaches and players when developing training programmes to optimise performance for the new game format including load management, substitution tactics and nutritional interventions.

Table 3. Mean ± standard deviation for the physiological demands of sub-elite male hockey players across playing positions.

Physiological demand	Playing Position			All
	Attackers	Midfielders	Defenders	
Mean HR (bpm)	167 ± 10	166 ± 8	167 ± 13	167 ±10
HRmax (bpm)	196 ± 12	191 ± 9	195 ± 11	194 ± 11
Band 1 (min: 65 - 75 %)	5 ± 6	4 ± 4	6 ± 5	5 ± 5
Band 1 (% time)	10 ± 11	9 ± 9	9 ± 7	10 ± 10
Band 2 (min: 75 - 85 %)	12 ± 6 [c]	13 ± 4 [c]	18 ± 8 [a,b]	14 ± 7
Band 2 (% time)	24 ± 11	26 ± 7	28 ± 10	26 ± 10
Band 3 (min: 85 - 95 %)	24 ± 9	26 ± 7	28 ± 7	26 ± 8
Band 3 (% time)	50 ± 16	54 ± 12	47 ± 12	50 ± 14
Band 4 (min: > 95%)	5 ± 6	4 ± 3	7 ± 7	5 ± 5
Band 4 (% time)	9 ± 10	7 ± 6	12 ± 13	9 ± 10
Percentage Time > 85% HRmax (%)	58 ± 20	61 ± 15	59 ± 19	60 ± 18

a = significantly different to attackers ($p < 0.001$), b = significantly different to midfielders ($p < 0.008$), c = significantly different to defenders ($p < 0.05$).

Table 4. **Mean ± standard deviation for the physiological demands of sub-elite hockey players across playing positions and match quarters.**

Physiological demands	Match Quarter			
	Q1	Q2	Q3	Q4
Band 1 (min: 65 - 75 %)	1 ± 1+	1 ± 1+	1 ± 2	2 ± 2^,#
Band 2 (min: 75 - 85 %)	3 ± 2*,+	3 ± 2 *,+	4 ± 2^,#	4 ± 2^,#
Band 3 (min: 85 - 95 %)	7 ± 3*	7 ± 3*	6 ± 3^,#	6 ± 3
Band 4 (min: > 95%)	2 ± 2*,+	1 ± 2	1 ± 2^	1 ± 1^
Percentage Time > 85% HRmax (%)	67 ± 19	66 ± 20	54 ± 21	54 ± 24

^ = significantly different to Q1 ($p < 0.05$), # = significantly different to Q2 ($p < 0.05$), * = significantly different to Q3 ($p < 0.05$), + = significantly different to Q4 ($p < 0.05$).

Although time-motion analysis studies exist for field hockey, some may be deemed outdated due to the new four-quarter match structure that has been implemented. Since the rule change, Ihsan et al. (2021) has reported that elite male hockey players cover 8387 ± 578 m during a match. In their study however, they calculated TD as if the player had participated in the full 60 min rather than their actual playing time and actual TD. Players in the current study covered a total of 5986 ± 1105 m in an average playing time of 52 ± 11 min, giving a RTD of 116 ± 12 m.min^{-1}. The two results are difficult to compare as Ihsan et al. (2021) over-estimate the true TD of players. Morencos et al. (2017) observed distances between 1800 - 2000 m per quarter which is again higher than the 1450 - 1600 m found in this study. However, in Morencos et al. (2017) study players played 3 - 6 minutes longer per quarter than players in the current study.

Activity profiles can be analysed further when broken down into the intensities in which they were performed. It is important to understand running intensity during a match as opposed to TD alone to give a reference point for training intensity as it can be used to determine the absolute stress placed on players (Casamichana et al., 2018). In the current study, players covered 38% (2246 ± 590 m) of TD walking, 44% (2660 ± 552 m) jogging, 16 % (979 ± 272 m) running, and 2% (90 ± 56 m) sprinting. This is in line with previous research showing that most time during a match is spent in low intensity activity both before (Macutkiewicz and Sunderland, 2011) and after the rule change (McMahon and Kennedy, 2019). Direct comparisons of velocity bands, however, is difficult due to the definitions of low intensity, moderate intensity and high intensity activity used amongst the literature. In the studies that have focussed on men's hockey since the introduction of the four-quarter format, Ihsan et al. (2021) identified low intensity activity as ≤ 15 km.h^{-1} and high intensity activity as ≥ 15 km.h^{-1} while Morencos et al. (2017) used standing-walking (< 9.0 km.h^{-1}), jogging (9.1 - 15.0 km.h^{-1}), moderate speed running (15.1 - 18.9 km.h^{-1}), high-speed running (>19 km.h^{-1}), and sprinting (> 23.0 km.h^{-1}), of which high-speed running and sprinting were grouped as high intensity exercise. Neither study gives values for total distance in the activity intensities, instead reporting values split by playing position.

Positional activity profiles of field hockey players have been previously reported with DEF having been found to cover the most total distance in match-play (McGuinness et al., 2019a; Sunderland and Edwards, 2017). DEF have also, however, been reported to play the most minutes in a match. Results from this study identified that DEF (105 ± 13 m.min^{-1}) completed significantly less RTD when compared to ATT (120 ± 10 m.min^{-1}) and MID (120 ± 9 m.min^{-1}) agreeing with literature conducted after the rule change (Morencos et al., 2017). ATT covered more high-speed distance than both MID and DEF evident in the results for both band 4 (ATT: 1104 ± 261 m; MID: 1104 ± 261 m; DEF: 865 ± 361 m) and band 5 (ATT: 109 ± 62 m; MID: 84 ± 45 m; DEF: 84 ± 45) velocities in this study. Although direct comparisons with previous literature can be difficult due to different methodologies or velocity zones being used, research seems to report similar results and ATT are generally reported to perform the most HIA in field-hockey matches (Ihsan et al., 2021; Morencos et al., 2017; Sunderland and Edwards, 2017). These results are likely because of positional roles; ATT tend to sprint faster and more often as they try to seek the ball and scoring opportunities (Vescovi, 2015) whereas DEF may hold positions in order to stop goal scoring opportunities rather than following the ATT (Harry and Booysen, 2020). The implications of this could mean different conditioning programmes are required for the differing positions to reduce injury risk and improve positional performance.

We found no significant difference in TD covered between the four quarters of a match. Prior to the rule change, Jennings et al. (2012), Liu et al. (2013), and Lythe and Kilding (2013) identified a decrease in TD for international players between the first and second halves of a match, with all authors attributing the decline to lower high-speed running in the second half. In the present study, no significant difference was identified in high-speed running over the quarters of the match although a significant decline in MIA (8.1 - 15.5 km.h^{-1}) between Q4 and Q1-2 was found. Our results could therefore suggest that players are sacrificing moderate intensity activity to retain high intensity performance for the duration of a match. The additional breaks which have been introduced in the game may have allowed players to perform at a higher intensity for the duration of a match as outlined by McMahon and Kennedy (2019). It is also possible that the game has been tactically altered with a higher rate of substitutions (McMahon and Kennedy, 2019) and these changes are responsible for the current performance profiles. Substitutions have been shown to offset decrements in physical output rather than improve physical outputs (Lythe and Kilding, 2011). In the present study a difference was identified in RTD between the quarters of play. RTD in Q4 (113.5 ± 14.5 m.min^{-1}) was lower than both Q1 (119.8 ± 17.4 m.min^{-1}) and Q2 (119.2 ± 15.7 m.min^{-1}). As there was no difference noted in TD this potentially means that players are playing more minutes in the final quarter which, as suggested by Lythe and Kilding (2013), could be a tactical change to offset decrements in performance in the final minutes of a game by increasing substitutions. Future research is warranted on the use of substitutions within field hockey and their impact on performance output.

To the authors knowledge, this is the first study to report the HR of male hockey players since the introduction of the four-quarter match format in the English National Hockey League. Understanding an athlete's physiological response to an exercise stimulus can help aid the training of the cardiovascular system with particular focus on HR training loads within the sport (Polglaze et al., 2018). Physiologically focussed training drills can then be implemented which elicit an intended training load response (Perrotta et al., 2019). The results from this study show that players spent 60 ± 18 % of their total match-play time at over 85% of HR_{max}. This agrees with previous literature conducted before the rule change (Harry and Booysen, 2020; Lythe and Kilding, 2013) and highlights the demands a hockey match places on the aerobic systems of players. It does not however, show that the new match format has made the game any more intense than it was previously. Average HR and HR_{max} for all players was found to be 167 ± 10 bpm and 194 ± 11 bpm respectively which is similar to HR data from female players reported before and after the rule change (McGuinness et al., 2019b; Sell and Ledesma, 2016), and from male players reported prior to the rule change (Buglione et al., 2013). There were no significant differences in average HR or HR_{max} across the three playing positions however it was identified that DEF (18 ± 8 min) spent significantly more time in HR band 2 (75 - 85 % HR_{max}) compared to both ATT (12 ± 6 min) and MID (13 ± 4 min). The reason for this is likely to be the longer amount of time DEF spent on the pitch in a match (significantly more when compared to ATT and MID) as there were no differences found when the percentage of TT spent in all HR bands was analysed. These findings agree with previous literature that playing position does not influence HR response in field hockey players (Konarski, 2010; Sell and Ledesma, 2016) and suggests no differences in HR data due to the new match format in relation to playing position.

Although positional differences were not found in this study, there were differences identified when HR was analysed over the four quarters of a match. Average HR was found to be significantly lower in Q3 (164 ± 11 bpm) and Q4 (164 ± 11 bpm) compared to Q1 (169 ± 11 bpm) and Q2 (168 ± 11 bpm) and HR_{max} was significantly higher in Q1 (191 ± 10 bpm) compared to Q3 (187 ± 12 bpm) and Q4 (187 ± 13 bpm). Time in HR band 3 (85 – 95 % HR_{max}) was found to be lower in Q3 (6 ± 3 min) than in both Q1 (7 ± 3 min) and Q2 (7 ± 3 min). Considering the running activity profiles mentioned earlier and these results, it is possible that training methods have been adapted for the new match format, which could explain why high intensity running does not change but HR decreases. Another possibility could be the additional breaks may be allowing players to recover more efficiently and therefore maintain high intensity in the final quarter. As this is the first study to identify physiological profiles of male field hockey players across four quarters there is little research to compare these results to. McGuinness et al. (2019a) found that elite female players showed an increase in % HR_{max} between Q2 and Q3 when compared to Q1, and a significant decrease in the time spent > 70 % HR_{max} between Q2 and Q4 compared to Q1. This shows similar trends between the two studies however there is more research required in this area to allow for conclusions to be made on the true physiological demands of the game and therefore inform training.

The results show that on average players cover a TD of 5986 ± 1105 m during a match with DEF covering the lowest RTD and ATT covering more distance in high velocity zones (running and sprinting). There was no difference noted in TD covered between the quarters of the match, however there was a decline in RTD possibly suggesting tactical implementation towards the end of a match. HIA did not decrease over the four quarters of a match however HR showed a decline in Q3 and Q4 compared to Q1 and Q2 perhaps indicating the additional breaks within the game are allowing players more efficient recovery during a match. It would be beneficial for more physiological indicators to be measured in future research to strengthen knowledge in this area.

There are limitations of the present study which should be considered when interpreting the results. Tactics for either team were not accounted for, and oppositional play has been shown to affect playing performance (Higham et al., 2012) along with opponent ranking (James et al., 2022). The match score line, and venue (home or away) are also not reported; these variables could have an influence on the locomotor activity of players. Whilst this paper used more traditional statistical analysis methods in line with similar research in this area (Ihsan et al., 2021; McGuinness et al., 2019a), further research could explore these additional variables using more contemporary analysis methods such as linear mixed models as shown in (Cunniffe et al., 2022; Brocherie et al., 2015). With limited research in male field hockey, and the seemingly regular introduction of rule changes, it is important that more research is conducted to identify the true locomotor activity profiles of the sport both physically and physiologically perhaps using different parameters to those already reported. Future research could focus not only on locomotor and physiological profiles, but biomechanics as well.

Conclusion

The current study outlines the physical and physiological activity profiles of national-level male field hockey players across playing positions as well as quarters of play with the results highlighting a need to consider positional differences when implementing a training programme for players, not just at elite level. The study identifies that the new four-quarter match format changes the locomotor activity profiles of the game with players covering 116 ± 12 $m.min^{-1}$ and 21.4 ± 6.8 $m.min^{-1}$. Coaches in teams which move to the four-quarter format should use this information when designing training sessions as well as when employing tactical changes within a match. This is the first study to identify the HR of male field hockey players across 4 quarters of a hockey match. Differences were identified both within positions as well as across the quarters of the match with defenders spending more time at 75% - 85% HR_{max} and all players having a lower mean HR in Q3 & Q4 compared to Q1 and Q2. Coaches and applied practitioners can use this information to specify their training programmes and better simulate match-play.

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References

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W. and Cable, N. T. (2017) Monitoring athlete training loads: Consensus statement. *International Journal of Sports Physiology and Performance* **12(2)**, 161-170. https://doi.org/10.1123/IJSPP.2017-0208

Brocherie, F., Girard, O., Farooq, A. and Millet, G.P. (2015) Influence of weather, rank, and home advantage on football outcomes in the gulf region. *Medicine & Science in Sports & Exercise* **47(2)**, 401-410. https://doi.org/10.1249/MSS.0000000000000408

Buglione, A., Ruscello, B., Milia, R., Migliaccio, G. M., Granatelli, G. and D'Ottavio, S. (2013) Physical and physiological demands of elite and sub-elite Field Hockey players. *International Journal of Performance Analysis in Sport* **13(3)**, 872-884. https://doi.org/10.1080/24748668.2013.11868695

Casamichana, D., Morencos, E., Romero-Moraleda, B. and Gabbett, T. J. (2018) The use of generic and individual speed thresholds for assessing the competitive demands of field hockey. *Journal of Sports Science and Medicine* **17(3)**, 366-371. https://pubmed.ncbi.nlm.nih.gov/30116109/

Cohen, J. (1992) A Power Primer. *Psychological Bulletin* **112(1)**, 155-159. https://doi.org/10.1037/0033-2909.112.1.155

Cunniffe, E., Connor, M., Beato, M., Grainger, A., McConnell, W., McCarthy Persson, U., Delahunt, E., Boreham, C. and Blake, C. (2022) The influence of possession status on the physical output of male international hockey players. *International Journal of Sports Science & Coaching* **17(2)**, 412-422. https://doi.org/10.1177/17479541211033958

Dwyer, D. B. and Gabbett, T. J. (2012) Global positioning system data analysis: Velocity ranges and a new definition of sprinting for field sport athletes. *Journal of Strength and Conditioning Research* **26(3)**, 818-824.

England Hockey,. (2019) http://www.englandhockey.co.uk/

Harry, K. and Booysen, M. J. (2020) Faster heart rate recovery correlates with high-intensity match activity in female field hockey players - training implications. *Journal of Strength and Conditioning Research* **34(4)**, 1150-1157. https://doi.org/10.1519/JSC.0000000000003073

Higham, D. G., Pyne, D. B., Anson, J. M. and Eddy, A. (2012) Movement patterns in rugby sevens: Effects of tournament level, fatigue and substitute players. *Journal of Science and Medicine in Sport* **15(3)**, 277-282. https://doi.org/10.1016/j.jsams.2011.11.256

Hoppe, M. W., Baumgart, C., Polglaze, T. and Freiwald, J. (2018) Validity and reliability of GPS and LPS for measuring distances covered and sprint mechanical properties in team sports. *Plos One* **13(2)**, e0192708-e0192708. https://doi.org/10.1371/journal.pone.0192708

Ihsan, M., Yeo, V., joseph, R., Lee, M. and Aziz, A. R. (2021) Running demands and activity profile of the new four-quarter match format in men's field hockey. *Journal of Strength and Conditioning Research* **35(2)**, 512-518. https://doi.org/10.1519/JSC.0000000000002699

International Hockey Federation,. (2019) http://fih.ch/?redirect=internal

James, C. A., Gibson, O. R., Dhawan, A., Stewart, C. M. and Willmott, A. G. B. (2021) Volume and intensity of locomotor activity in international men's field hockey matches over a 2-year period. *Frontiers in Sports and Active Living* **3**. https://doi.org/10.3389/fspor.2021.653364

James, C.A., Gibson, O.R., Willmott, A.G.B., Stewart, C. and Dhawan, A. (2022) Relationships between opponent ranking and locomotor activity in international field hockey. *International Journal of Sports Science & Coaching*. https://doi.org/10.1177/17479541221131773

Jennings, D. H., Cormack, S. J., Coutts, A. J. and Aughey, R. J. (2012) International field hockey players perform more high-speed running than national-level counterparts. *Journal of Strength and Conditioning Research* **26(4)**, 947-952. https://doi.org/10.1519/JSC.0b013e31822e5913

Konarski, J. (2010) Characteristics of chosen parameters of external and internal loads in Eastern European high level field hockey players. *Journal of Human Sport and Exercise* **5(1)**, 43-58. https://doi.org/10.4100/jhse.2010.51.06

Kusnanik, N. W., Rahayu, Y. S. and Rattray, B. (2018) Physiological Demands of Playing Field Hockey Game at Sub Elite Players. *IOP Conference Series: Materials Science and Engineering* **288(1)**, 12112. https://doi.org/10.1088/1757-899X/288/1/012112

Liu, H., Zhao, G., Gómez, A. M., Molinuevo, S. J., Giménez, J. V. and Kang, H. (2013) Time-motion analysis on Chinese male field hockey players. *International Journal of Performance Analysis in Sport* **13(2)**, 340-352. https://doi.org/10.1080/24748668.2013.11868652

Lythe, J. and Kilding, A. E. (2011) Physical demands and physiological responses during elite field hockey. *International Journal of Sports Medicine* **32(7)**, 523-528. https://doi.org/10.1055/s-0031-1273710

Lythe, J. and Kilding, A. E. (2013) The effect of substitution frequency on the physical and technical outputs of strikers during field hockey match play. *International Journal of Performance Analysis in Sport* **13(3)**, 848-859. https://doi.org/10.1080/24748668.2013.11868693

Macutkiewicz, D. and Sunderland, C. (2011) The use of GPS to evaluate activity profiles of elite women hockey players during match-play. *Journal of Sports Sciences* **29(9)**, 967-973. https://doi.org/10.1080/02640414.2011.570774

Malone, J., Lovell, R., Varley, M. C. and Coutts, A. J. (2017) Unpacking the black box: Applications and considerations for using GPS devices in sport. *International Journal of Sports Physiology and Performance* **12**, 18-26. https://doi.org/http://dx.doi.org/10.1123/ijspp.2016-0236

McGuinness, A., Malone, S., Hughes, B. and Collins, K. (2019a) The physical activity and physiological profiles of elite international female field hockey players across the quarters of competitive match play. *Journal of Strength and Conditioning Research* **33(9)**, 2513-2522. https://doi.org/10.1519/JSC.0000000000002483

McGuinness, A., Malone, S., Petrakos, G. and Collins, K. (2019b) The physical and physiological demands of elite international female field hockey players during competitive match-play. *Journal of Strength and Conditioning Research* **33(11)**, 3105-3113. https://doi.org/10.1519/JSC.0000000000002158

McMahon, G. E. and Kennedy, R. A. (2019) Changes in player activity profiles after the 2015 FIH rule changes in elite women's hockey. *Journal of Strength and Conditioning Research* **33(11)**, 3114-3122. https://doi.org/10.1519/jsc.0000000000002405

Morencos, E., Romero-Moraleda, B., Castagna, C. and Casamichana, D. (2017) Positional comparisons in the impact of fatigue on movement patterns in hockey. *International Journal of Sports Physiology and Performance* **13(9)**, 1149-1157. https://doi.org/10.1123/ijspp.2017-0506

Perrotta, A. S., Held, N. J. and Warburton, D. E. R. (2017) Examination of internal training load parameters during the selection, preparation and competition phases of a mesocycle in elite field hockey players. *International Journal of Performance Analysis in Sport* **17(5)**, 813-821. https://doi.org/10.1080/24748668.2017.1402284

Perrotta, A. S., Taunton, J. E., Koehle, M. S., White, M. D. and Warburton, D. E. (2019) Monitoring the prescribed and experienced heart rate–derived training loads in elite field hockey players. *Journal of Strength and Conditioning Research* **33(5)**, 1394-1399. https://doi.org/10.1519/JSC.0000000000002474

Polglaze, T., Hogan, C., Dawson, B., Buttfield, A., Osgnach, C., Lester, L. and Peeling, P. (2018) Classification of intensity in team sport

activity. *Medicine & Science in Sports & Exercise* **50(7)**, 1487-1494. https://doi.org/10.1249/MSS.0000000000001575
Sell, K. M. and Ledesma, A. B. (2016) Heart rate and energy expenditure in division I field hockey players during competitive play. *Journal of Strength and Conditioning Research* **30(8)**, 2122-2128. https://doi.org/10.1519/jsc.0000000000001334
Sunderland, C. and Edwards, P. (2017) Activity profile and between-match variation in elite male field hockey. *Journal of Strength and Conditioning Research* **31(3)**, 758-764. https://doi.org/10.1519/JSC.0000000000001522
Vescovi, J. D. (2015) Motion characteristics of division I college field hockey: Female Athletes in Motion (FAiM) Study. *International Journal of Sports Physiology and Performance* **10**, 476-481. https://doi.org/10.1123/ijspp.2014-0324
White, A. D. and MacFarlane, N. (2013) Time-on-pitch or full-game GPS analysis procedures for elite field hockey. *International Journal of Sports Physiology and Performance* **8**, 549-555. https://doi.org/10.1123/ijspp.8.5.549

Key points

- This study provides novel normative data on the physical and physiological demands of elite domestic male field hockey players across playing positions as well as quarters of play.
- The data in this paper could be beneficial to practitioners and coaches working in elite domestic field Hockey, as this can be used to inform training programmes, nutritional requirements, and match tactics (i.e., substitutions).
- Our findings suggest that position specific training programmes would best replicate the demands of each position. The data could also help coaches to develop tactical substitution protocols during matches.
- This is the first study to report the heart rate of male hockey players since the introduction of the four-quarter match format in the English National Hockey League. Understanding an athlete's physiological response to an exercise stimulus can help aid the training of the cardiovascular system with particular focus on heart rate training loads within the sport.

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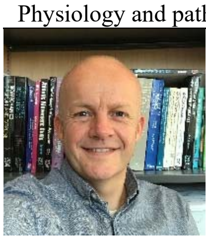

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