PHYSICAL, PHYSIOLOGICAL DEMANDS AND MOVEMENT PROFILES OF PROFESSIONAL MEN'S FIELD HOCKEY GAMES

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Abstract:

The aim of this study was to investigate physical demands, physiological demands, and movement profiles of different positions across four quarters in professional men's field hockey games. Eighteen professional male field hockey players participated in the study, and data were collected in eleven official matches. Players wore global positioning system units and heart rate monitors to collect physical, physiological, and movement profile data. Defenders had significantly higher absolute total distance covered, player load, acceleration and deceleration count, and forward-backward initial movement analysis (IMA) count, but lower high speed running distance, compared with midfielders and forwards ($p<.05$). However, when using relative metrics (normalised by playing time), defenders had the lowest physical and physiological outputs, and forwards had the highest ($p<.05$). Total distance covered per minute, high-speed running distance per minute, player load per minute, acceleration and deceleration count per minute, and repeated high-intensity efforts per minute were all significantly higher in quarter 1 than in other three quarters ($p<.05$). The percentages of linear running and non-linear dynamic movement duration decreased quarter by quarter. Modified training impulse per minute reached its peak in quarter 2 ($p<.05$). It was concluded that defenders had the highest volume in terms of the game demands due to their high playing minutes; however, they had the lowest relative volume compared with the other two positions. Forwards had the highest linear running intensity, while midfielders were required to perform more multi-directional, non-linear movements. Quarter 1 was the most active quarter and players became fatigued in quarter 2. IMA counts were not sensitive to fatigue compared to movement profile and modified training impulse variables.

Key words: *GPS, activity profile, heart rate, team sports*

Introduction

Using athlete tracking technologies to monitor performance in team sports has become increasingly common in order to gain insights into game demands, mitigate risks of injury, and quantify training load (Torres-Ronda, Beanland, Whitehead, Sweeting, & Clubb, 2022). Positioning information such as distance covered and speed can be reported by using the Global Positioning System (GPS), and GPS units for performance tracking purposes are usually embedded with other sensors such as accelerometer, magnetometer, and gyroscope to quantify explosive movements such as change of directions (COD), jumps, and movement patterns (Chambers, Gabbett, Cole, & Beard, 2015; Lutz, Memmert, Raabe, Dornberger, & Donath, 2019; Szigeti, Schuth, Kovacs, Pavlik, & Barnes, 2021).

In recent studies on physical demands of field hockey games, the commonly used variables are total distance covered and distance in each speed zone. There are also a number of studies that investigated the numbers of accelerations and decelerations, heart rate variables (Lim, Sim, & Kong, 2021), and player load (McMahon & Kennedy, 2019a; White & MacFarlane, 2013). The comparisons were made among different playing positions (Dewar & Clarke, 2021; Harry & Booysen, 2020; Ihsan, et al., 2021; James, Gibson, Dhawan, Stewart, & Willmott, 2021; Kapteijns, Caen, Lievens, Bourgois, & Boone, 2021; McGuinness, Malone, Petrakos, & Collins, 2019; McGuinness, Passmore, Malone, & Collins, 2020; Morencos, Romero-Moraleda, Castagna, & Casamichana, 2018; Vescovi, 2016), different playing rules (McMahon & Kennedy, 2019a), and different competition levels (Vinson, Gerrett, & James, 2018). After the 2015 change of rules of field hockey games, there were only a few studies on the physiological demands using heart rate data. Currently, the elite game heart rate data were only reported in women's games (McGuinness, Kenna, Grainger, & Collins, 2021; McGuinness, Malone, Hughes, Collins, & Passmore, 2019; Sell & Ledesma, 2016; Vescovi, 2016). There was only one study that investigated the heart rate data for men's team, however, the participants in the study were student athletes, not professional athletes. Meanwhile, the game format was different from the standard Federation of International Hockey (FIH) rules (Lam, et al., 2021). Field hockey is a fast-paced and intermittent team sport that allows unlimited substitutions during the game. Due to its nature with repeated high-intensity bouts, there has been an increased focus on monitoring not only locomotive running load, but also the count of accelerations and decelerations (Harry & Booysen, 2020; Morencos, et al., 2018). Traditionally, these metrics are quantified by GPS which has its limitations when it comes to accurately measuring short, sharp changes in actions (i.e., explosive change of directions) (Malone, Lovell, Varley, & Coutts, 2017; Szigeti, et al., 2023). Therefore, only looking at GPS-derived data (i.e., linear running distance) will be underestimating the physical demands of field hockey games. Movement profile is quantified by inertial sensors which have been shown to have good reliability and validity and it could differentiate between linear running and dynamic movements (Szigeti, et al., 2021, 2023). Understanding the movement profiles of different positions provides additional insight into the multi-directional component of the field hockey game, which could further inform practitioners when it comes to load management.

The objectives of the current study are: 1) to investigate the physical demands, physiological demands, and movement profiles across different position groups in professional men's field hockey games; 2) to investigate the changes in physical performance, physiological performance, and movement profiles across quarters in professional men's field hockey games and identify fatigue indicators.

Methods

Participants

Eighteen professional male field hockey players (age 25.6 ± 2.5 years, body height 171.8 ± 5.2 cm, body mass 70.1 ± 7.5 kg) participated in the study, including seven forwards, six midfielders, and five defenders. Participants worked full-time as professional athletes and trained at least five days per week, two sessions per day throughout the year. The team won the National Games championship and represented the highest competition level of the country. Prior to the data collection, all athletes were verbally informed of the purpose, procedures, risks, and benefits of the research, and written informed consent forms were signed. The research was approved by the Ethics Committee of Guangdong Institute of Sport Science.

Measures

The physical data and movement profile data were collected using GPS technology integrated with inertial sensors (Vector S7, Catapult Sports, Melbourne, Australia, Firmware Version 8.1). The GPS sampling frequency was 10 Hz, and the inertial sensor sampling frequency was 100 Hz. The physiological data were collected using heart rate monitors (Polar H1 chest strap, Polar Electro Oy, Kempele, Finland). The validity and reliability of both devices have been reported acceptable (Clavel, et al., 2022; Crang, et al., 2022; Schaffarczyk, Rogers, Reer, & Gronwald, 2022). Both physical, physiological, and movement profile data were processed in OpenField (Catapult Sports, Melbourne, Australia, Version 3.3.1).

The physical demand metrics reported were:

- Total distance (m) and distance per minute ($mmin^{-1}$);
- High-speed running distance (m, HSRD) and HSRD per minute ($mmin^{-1}$), threshold set as > 15 kmh^{-1};
- Inertial movement analysis count (n, IMA) and IMA count per minute ($nmin^{-1}$) in each direction at medium and high intensity. IMA uses inertial sensors to detect instant one-step movement efforts (e.g., sudden change of direction). The direction of an IMA event is calculated relative to the device's orientation at the time of the step and is measured in degrees. IMA counts were categorised into medium (2.5 to 3.5 $m \cdot s^{-1}$) and high (>3.5 $m \cdot s^{-1}$) intensities, and were also categorised into four directions, which include forward (-45 to 45 degrees), backward (-135 to 135 degrees), left (-135 to -45 degrees) and right (45 to 135 degrees). Luteberget, Holme, and Spencer's (2018) study showed that IMA count is a reliable variable in reporting the physical demands in team sports. In the current study, four categories of IMA counts were reported: total high intensity IMA count (total high IMA count), total medium and high IMA count (total MedHigh IMA count), medium and high intensity forward and backward IMA count (MedHigh FB IMA count), medium and high intensity left and right IMA count (MedHigh LR IMA count);
- Repeated high-intensity efforts (RHIE, n) and RHIE per minute ($mmin^{-1}$). One RHIE was registered when there were three consecutive

high-speed runs, and the recovery interval between each two high-speed runs were less than 21 seconds;

- Player load (au) and player load per minute (au). Player load was derived from the accelerometer in the GPS unit, sampling at 100 Hz, being the sum of the accelerations across all axes of the internal tri-axial accelerometer during movement. It takes into account the instantaneous rate of change of acceleration and divides it by a scaling factor (divided by 100). Player load reports the total external mechanical stress accumulated and was reported as a valid and reliable metric (Barrett, 2017; Lutz, et al., 2019);
- Accelerations and decelerations count (n, AccDec count) and AccDec count per minute ($nmin^{-1}$), threshold set as $> 2\ ms^{-2}$;

The movement profile metrics reported were:

- Duration percentage in each movement type (%). Movement profiles were categorised into four types:
    1) Static: when the athlete is static, standing still, or of minimal movement;
    2) Walking: when the athlete is walking, or of low intensity movement;
    3) Linear running: when the athlete is running in linear line;
    4) Non-linear dynamic movements: when the athlete is moving multi-directionally.

The movement profile categories were based on player load values, which had previously been shown to be a valid and reliable metric (Barrett, 2017).

The physiological demand metrics reported were:

Average heart rate (beat per minute, Avg. HR);

- Relative average heart rate (%, Avg. HR%), the individualised average heart rate calculated from each individual's maximal heart rate;
- Duration percentage in each heart rate zone (%), the percentage of the time spent in each heart rate zone compared to the total field time. Zone 1: 65-71% HR_{max}, Zone 2: 72-78% HR_{max}, Zone 3: 79-85% HR_{max}, Zone 4: 86-92% HR_{max}, Zone 5: 93-100% HR_{max};
- Modified training impulse (au, $TRIMP_{mod}$) and $TRIMP_{mod}$ per minute (au). $TRIMP_{mod}$ is a method adopted from previous research to quantify the internal load of intermittent team sports. $TRIMP_{mod}$ was calculated by multiplying the weighting factors by the time spent in the respective heart rate zones, and summing them up (Stagno, Thatcher, & van Someren, 2007). Heart rate zones, weighting factors, and training descriptors are shown in Table 1.

The individual maximal heart rate was collected from all the YOYO IR2 tests, training and games in the 12-month period prior to the tournament. Research shows that the maximal heart rate collected from the YOYO IR2 tests has no difference from the maximal heart rate collected from conventional laboratory treadmill incremental tests to exhaustion (Bradley, et al., 2011).

Design and procedures

The data were collected from 18 professional male field hockey players in 11 official games in the National Games Series. The players were categorised into three positions: forward, midfielder, and defender. Overall, there were 169 observations included in the dataset (64 for forwards, 62 for midfielders, and 43 for defenders).

Every player wore his own GPS unit, GPS vest, and heart rate straps throughout the tournament to ensure consistency. Prior to each game, the GPS units were turned on at least fifteen minutes before warming up and the heart rate sensors were moisturised per the manufacturers' instructions to ensure optimal data quality. The average number of satellites connected was 14.99±1.66, and the average horizontal dilution of precision (HDOP) was 0.73±0.08, which was considered good satellite signal quality (Malone, et al., 2017). The data were processed and trimmed according to the actual playing time of the players: the between-quarter breaks, off-pitch time, and video review time were excluded from the analysis.

Statistical analysis

Data are expressed as mean ± standard deviation. The repeated measures ANOVA was used to determine the differences across positions and quarters. In the event of a significant difference, the Bonferroni *post-hoc* test was used. Statistical

Table 1. The heart rate zones, weighting factors, and training descriptors of modified training impulse calculation

Zone	% maximal heart rate	Weighting factor	Training type
1	65-71	1.25	Moderate activity
2	72-78	1.71	Lactate threshold training
3	79-85	2.54	Steady-state training
4	86-92	3.61	OBLA training
5	93-100	5.16	Maximal training

Note. Adopted from Stagno et al., 2007

significance was set at p<.05. All statistical analyses were conducted using IBM SPSS Statistics (IBM Corp., Armonk, USA, Version 27).

Results

Full-game positional differences

The game average physical demands in absolute values of different positions are presented in Table 2. The field time of defenders was significantly higher than the time of midfielders and forwards. In terms of the physical demands in absolute values, total distance, player load, AccDec count, and MedHigh FB IMA count of defenders were significantly higher than those of forwards and midfielders (p<.05); however, high-speed running distance of defenders was significantly lower than the one of forwards and midfielders (p<.05). Total high IMA count, total MedHigh IMA count, and MedHigh LR IMA count of defenders were significantly higher than those of forwards (p<.05).

The game average physical demands in relative values of different positions are presented in Table 3. For distance per minute, HSRD per minute, player load per minute, and RHIE per minute, the data were significantly different across all the positional groups, where forwards had the highest numbers and defenders had the lowest values (p<.05). AccDec count per minute of defenders was significantly lower than that of forwards and midfielders (p<.05), and the MedHigh LR IMA count per minute of defenders was significantly lower than that of forwards (p<.05).

The game average movement profiles of different positions are presented in Table 4 and Figure 1. There were significant differences across all the positions for static duration% and non-linear dynamic movement duration% (p<.05). Walking duration% of defenders was significantly higher than it was in midfielders and forwards, while linear running duration% of defenders was significantly lower than that of midfielders and forwards (p<.05).

Table 2. Game average physical demands in absolute values for different playing positions

	Midfielders	Forwards	Defenders
Field time (min)	38.7±3.3	36.2±1.4	63.4±8.2[a]
Total distance (m)	4788±237	4700±262	6252±908[a]
High-speed running distance (m)	1142±128	1213±155	947±242[a]
Player load (au)	471±34	503±27	605±90[a]
AccDec count (n)	217±24	206±17	266±43[a]
RHIE count (n)	25.4±1.3	26.3±2.1	29±8.4
Total high IMA count (n)	18.6±7	15.3±2.6	24±8[b]
Total MedHigh IMA count (n)	70.6±25.5	59.1±8.1	87.8±23.4[b]
MedHigh BF IMA count (n)	23.2±9.1	22.1±2.3	33.6±9[a]
MedHigh LR IMA count (n)	47.3±16.7	36.9±5.9	54.2±14.9[b]

Note. Au – arbitrary units; AccDec count – accelerations and decelerations count; RHIE – repeated high-intensity efforts; IMA – inertial movement analysis; MedHigh – medium and high intensity; BF – backward and forward; LR – left and right; a indicates defenders were significantly different from midfielders and forwards (p<.05); b indicates forwards were significantly different from defenders (p<.05).

Table 3. Game average physical demands in relative values for different positions

	Midfielders	Forwards	Defenders
Distance per minute (mmin^{-1})	124±6	130±5	98±4[a]
HSRD per minute (mmin^{-1})	29.8±4.7	33.5±3.9	14.8±2.5[a]
Player load per minute (au)	12.2±0.7	13.9±0.6	9.5±0.6[a]
AccDec count per minute (nmin^{-1})	5.63±0.5	5.68±0.51	4.2±0.41[b]
RHIE count per minute (nmin^{-1})	0.66±0.06	0.72±0.05	0.45±0.09[a]
Total high IMA count per minute (nmin^{-1})	0.48±0.18	0.42±0.08	0.38±0.11
Total MedHigh IMA count per minute (nmin^{-1})	1.81±0.64	1.64±0.25	1.39±0.33
MedHigh FB IMA count per minute (nmin^{-1})	0.59±0.22	0.61±0.07	0.53±0.13
MedHigh LR IMA count per minute (nmin^{-1})	1.21±0.42	1.02±0.17	0.86±0.21[c]

Note. Au – arbitrary units; HSRD – high-speed running distance; AccDec count – accelerations and decelerations count; RHIE – repeated high-intensity efforts; IMA – inertial movement analysis; MedHigh – medium and high intensity; BF – backward and forward; LR – left and right; a indicates the data were significantly different amongst midfielders, forwards, and defenders (p<.05); b indicates defenders were significantly different from midfielders and forwards (p<.05); c indicates forwards were significantly different from defenders (p<.05).

Table 4. Game average movement profiles of different positions

	Midfielders	Forwards	Defenders
Static duration%	10.1±1.8	11±2.3	19.5±3.5 [a]
Walking duration%	38.4±1.4	34.5±1.4	41±1.3 [b]
Linear running duration%	15.7±1.6	19.7±1.7	11.6±1.2 [b]
Non-linear dynamic movement duration%	35.9±2.7	34.8±2.7	27.9±2.9 [a]

Note. a indicates the data were significantly different amongst midfielders, forwards, and defenders (p<.05); b indicates defenders were significantly different from midfielders and forwards (p<.05).

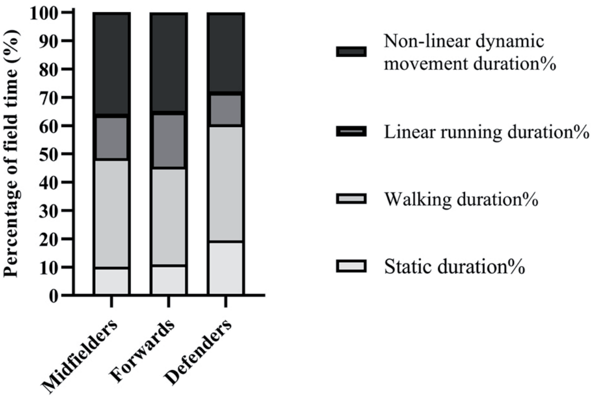

Figure 1. Movement profiles of each position.

The game average physiological demands of different positions are presented in Table 5. Average heart rate and $TRIMP_{mod}$ of defenders were significantly higher than it were in midfielders and forwards (p<.05), while their 72-78% HR_{max} duration%, 86-92% HR_{max} duration%, and $TRIMP_{mod}$ per minute were significantly lower than in midfielders and forwards (p<.05). Avg. HR% of forwards was significantly lower than that of midfielders and defenders, and their 65-71% HR_{max} duration% was significantly higher than in defenders (p<0.05).

Differences across quarters

Physical demands in relative values of four quarters are presented in Table 6. Distance per minute, HSRD per minute, player load per minute, AccDec count per minute, and RHIE per minute were all higher in quarter 1 compared with the other quarters (p<.05). There was no significant difference in all IMA variables. Distance per minute and player load per minute of quarter 2 were significantly higher than in quarter 4 (p<.05).

Movement profiles of four quarters are presented in Table 7 and Figure 2. Walking duration% in quarter 1 was significantly lower than in the other three quarters (p<.05), while linear running duration% and non-linear dynamic movement duration% were significantly higher than in the other three quarters (p<.05). Static duration% in quarter 2 was significantly higher than in quarter 4, while linear running duration% was significantly lower than in quarter 4 (p<.05).

Physiological demands of four quarters are presented in Table 8. 65-71% HR_{max} duration% and 72-78% HR_{max} duration% in quarter 1 were significantly higher than in quarters 3 and 4, and 86-92% HR_{max} duration% was significantly higher than in quarter 4 (p<.05). Average heart rate, 65-71% HR_{max} duration%, Avg. HR%, 72-78% HR_{max} duration%, 93-100% HR_{max} duration%, and $TRIMP_{mod}$ per minute were significantly higher in quarter 2 compared to quarters 3 and 4 (p<.05). 86-92% HR_{max} duration% in quarter 4 was significantly higher compared to quarters 1 and 2 (p<.05).

Table 5. Game average physiological demands of different positions

	Midfielders	Forwards	Defenders
Average heart rate (beat per minute)	161±3	162±3	166±4 [a]
Average heart rate%	88.9±2.7	81.6±2.4 [b]	86.8±2.3
65-71% HR_{max} Duration%	4.8±1.1	5.6±1	3.9±2.2 [c]
72-78% HR_{max} Duration%	9.3±1.7	9.6±1.3	7.3±2.7 [a]
79-85% HR_{max} Duration%	19.3±5.1	20.7±3.3	16.9±6.1
86-92% HR_{max} Duration%	42.4±6.6	41.8±3.4	34.5±6.4 [a]
93-100% HR_{max} Duration%	15.5±8.2	17.2±4.8	17.2±9.2
$TRIMP_{mod}$ (au)	118±9	115±7	175±41 [a]
$TRIMP_{mod}$ per minute (au)	3.04±0.28	3.16±0.18	2.74±0.47 [a]

Note. Au – arbitrary units; HR_{max} – maximal heart rate; $TRIMP_{mod}$ – modified training impulse; a indicates defenders were significantly different from midfielders and forwards (p<.05); b indicates forwards were significantly different from midfielders and defenders (p<.05); c indicates forwards were significantly different from defenders (p<.05).

Table 6. Physical demands in relative values of four quarters

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Distance per minute ($mmin^{-1}$)	126±4 [a]	118±8 [b]	115±7	111±7
HSRD per minute ($mmin^{-1}$)	28.3±2.9 [a]	25±3.3	25±3.9	24.6±3.6
Player load per minute (au)	13±0.7 [a]	11.9±1.1 [b]	11.5±0.9	11±0.9
AccDec count per minute ($nmin^{-1}$)	5.77±0.6 [a]	5.08±0.65	5.01±0.56	4.79±0.56
RHIE count per minute ($nmin^{-1}$)	0.67±0.06 [a]	0.6±0.1	0.6±0.06	0.58±0.05
Total high IMA count per minute ($nmin^{-1}$)	0.46±0.12	0.43±0.14	0.43±0.11	0.39±0.11
Total MedHigh IMA count per minute ($nmin^{-1}$)	1.8±0.41	1.6±0.39	1.57±0.38	1.5±0.36
MedHigh FB IMA count per minute ($nmin^{-1}$)	0.65±0.15	0.58±0.14	0.57±0.14	0.54±0.13
MedHigh LR IMA count per minute ($nmin^{-1}$)	1.15±0.27	1.03±0.27	1±0.25	0.96±0.25

Note. Au – arbitrary units; HSRD – high-speed running distance; AccDec count – accelerations and decelerations count; RHIE – repeated high-intensity efforts; IMA – inertial movement analysis; MedHigh – medium and high intensity; BF – backward and forward; LR – left and right; a indicates that quarter 1 was significantly different from quarter 2, quarter 3, and quarter 4 (p<.05); b indicates that quarter 2 was significantly different from quarter 4 (p<.05).

Table 7. Movement profiles of four quarters

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Static duration%	9.8±2.2 [c]	12.2±4.6 [b]	14.8±3.5	17.2±4.5
Walking duration%	36±1.4 [a]	39.2±2.1	38.1±2	38.8±2.1
Linear running duration%	17.7±1.7 [a]	15.7±1.6 [b]	15±2.1	13.6±1.5
Non-linear dynamic movement duration%	36.5±2.8 [a]	32.9±3.8	32±3.2	30.3±3.6

Note. a indicates that quarter 1 was significantly different from quarter 2, quarter 3, and quarter 4 (p<.05); b indicates that quarter 2 was significantly different from quarter 4 (p<.05); c indicates that quarter 1 was significantly different from quarter 3 and quarter 4 (p<.05).

Table 8. Physiological demands of four quarters

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Average heart rate (beat per minute)	164±3	166±3 [b]	161±3	163±3
Average heart rate%	84.3±2.8	85.6±2.2	83.6±3.4	83.6±2.9
65-71% HR_{max} Duration%	3.6±1 [a]	3.8±1.8 [b]	5.3±1.7	5.3±1.8
72-78% HR_{max} Duration%	7.3±1.9 [a]	7.1±1.6 [b]	9.6±2.4	9.8±2.7
79-85% HR_{max} Duration%	20±4.4	16.4±5.7	19.9±3.5	17.9±3.6
86-92% HR_{max} Duration%	41.7±3.2	40.9±4.5	39.5±7.7	35.7±4 [c]
93-100% HR_{max} Duration%	16.6±8.4	22.5±8.2 [b]	13.2±6.1	16±5.5
$TRIMP_{mod}$ (au)	3.04±0.31	3.23±0.31 [b]	2.85±0.34	2.81±0.25

Note. Au – arbitrary units; HR_{max} – maximal heart rate; $TRIMP_{mod}$ – modified training impulse; a indicates that quarter 1 was significantly different from quarter 3 and quarter 4 (p<.05); b indicates that quarter 2 was significantly different from quarter 3 and quarter 4 (p<.05); c indicates that quarter 4 was significantly different from quarter 1 and quarter 2 (p<.05).

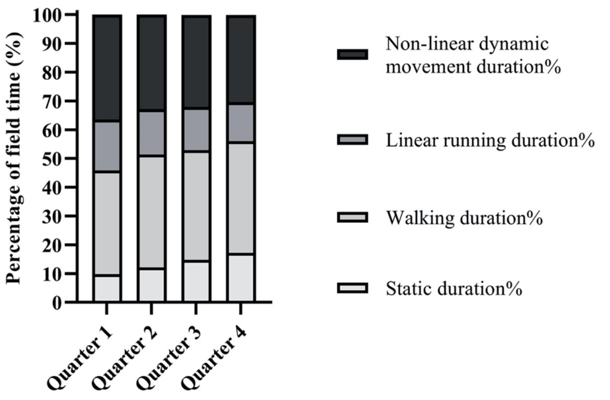

Figure 2. Movement profiles of each quarter.

Discussion and conclusions

The current study analysed the differences and changes in the physical demands, physiological demands, and movement profiles of professional men's field hockey players in different positions and quarters of the game. It is the first study that investigated the physiological demands and movement profiles in professional men's field hockey games under the standard FIH new rules. A detailed understanding of the differences between the load characteristics of different positions and different quarters of the game will help coaches to make informed decisions in squad selection and rotation strategies during the games, as well as drill prescription and load periodisation during the training, so to prepare the players for the game demands.

Positional differences

The results of the current study showed that defenders achieved 63.4 ± 8.2 min of field time, which was significantly higher than forwards and midfielders (36.2 ± 1.4 min and 38.7 ± 3.3 min, respectively). Similar results have been reported for longer playing time for defenders at international level (James, et al., 2021; McMahon & Kennedy, 2019b), due to the fact that coaches are usually less likely to rotate defenders during games. Defenders in the current study had the highest average total distance of 6252 ± 908 m, significantly higher than forwards and midfielders (4700 ± 262 m and 4788 ± 237 m, respectively). Ihsan et al. (2021) have reported that in the four-quarter format following the FIH new rule changes in 2015, forwards had the highest total distance (8922 ± 818 m), followed by midfielders (8613 ± 406 m), then defenders (7631 ± 753 m), which conflicts with the findings of the current study because the data in that study were not measured by the actual playing time, but rather based on the data divided by field time and then multiplied by 60 minutes to predict what players would run to if they played a full game. This prediction method ignored the effect of different playing times on the intensity of the game and may overestimate the game demands. Other studies that reported actual running values had produced results that match the current study, with defenders having the highest total distance covered and player load (James, et al., 2021; McMahon & Kennedy, 2019), due to the fact that defenders had the longest playing time. However, defenders had significantly lower HSRD (947 ± 242 m) than forwards and midfielders (1213 ± 155 m and 1142 ±128 m, respectively). These findings imply the need to use relative variables to describe load and game demands in field hockey studies, i.e., the total values divided by the actual playing time on the field, as there is no limit to the number of substitutions that can be made at any time during a field hockey game, and players may have different playing time and accumulate different amounts of load for the game. In the following analyses, the physical demands of the game are described in terms of relative values (normalised by actual playing time on the field).

In the running load category (total distance per minute, HSRD per minute, RHIE per minute), there were significant differences across all the positions and forwards achieved the highest values, while defenders had the lowest values. This indicates that the game places the highest demand on forwards to run, followed by the midfielders and the lowest demand on defenders, which is consistent with findings in other studies (Ihsan, et al., 2021; James, et al., 2021). In the mechanical load category (i.e., movements such as acceleration and deceleration, change of direction), AccDec count per minute was lower for defenders than for forwards and midfielders, while there was no significant difference between forwards and midfielders, but MedHigh LR IMA count per minute was significantly higher for midfielders. Movement profile analysis relies on inertial sensors in wearable devices to identify the types of movement (static, walking, linear running, non-linear dynamic movements) performed by players, and is an intuitive variable to indicate the proportion of time spent while executing each type of movement on the field (Szigeti, et al., 2021, 2023). In terms of the distribution of movement profiles across the game, defenders had the highest percentage of time spent static (19.5±3.5%), followed by forwards (11±2.3%), and the lowest percentage of time spent static had midfielders (10.1±1.8%). Defenders also had the highest percentage of time spent in walking (41±1.3%), significantly higher than forwards (34.5±1.4%) and midfielders (38.4±1.4%). Forwards had the highest percentage of time spent in linear (19.7±1.7%), while the midfielders had the highest percentage of time spent in non-linear dynamic movements (35.9±2.7%). These findings corroborate the above results for running load and mechanical load demands. This indicates that, in terms of the full game, defenders have lower demands than forwards and midfielders both in terms of running load and in terms of short, explosive mechanical load such as acceleration and deceleration, and change of direction. Forwards are more required to run lineary, including intensive high-speed running, while midfielders are more demanded in short, explosive mechanical load, especially lateral movements that require left and right changes of direction. Overall, judged by the comprehensive intensity indicator player load per minute, which takes into account all movements, forwards had the highest physical demands (13.9±0.6), followed by midfielders (12.2±0.7), and the lowest had defenders (9.5±0.6).

In the current study, individualised heart rate data were used to reflect the physiological demands in the games, where the individual maximal heart rate was derived from training, competition and YOYO IR2 tests over 12 months prior to data collection. The modified training impulse ($TRIMP_{mod}$) introduced by Stagno et al. (2007) was reported to be more appropriate to reflect the physiological load of intermittent team sports such as field hockey. The intensity of the physiological load was expressed in terms of $TRIMP_{mod}$ per minute based on the actual playing time of the players. Heart rate data processed in this way showed that defenders had a significantly lower $TRIMP_{mod}$ per minute than forwards and midfielders (2.74 ± 0.47, 3.16 ± 0.18, 3.04 ± 0.28, respectively). A breakdown of the time spent in each heart rate zone showed that 72-78% HR_{max} duration% and 86-92% HR_{max} duration% were significantly higher for forwards and midfielders than for defenders, suggesting that forwards and midfielders should focus more on lactate threshold and anaerobic threshold training compared to defenders. There was no significant difference in 93-100% HR_{max} duration% across the three positions, suggesting that none of the three positions, especially defenders, should neglect the maximal intensity training. Combining the above analysis of external physical demands and internal physiological demands, it can be concluded that forwards have the highest game demands in both external physical load and internal physiological load, while defenders have relatively lower physical demands.

There could be several contributing factors causing the positional differences. McMahon et al. (2019) and James et al. (2021) both found significant differences in the playing time between forwards, midfielders and defenders, with the basic pattern being that defenders had the longest playing time and forwards the shortest, which is consistent with the findings of the current study. James et al. (2021) also found a strong negative relationship between total playing time and average speed of play in their study. The fewer the rotations, the longer playing time during the game, which would result in decreased intensity, both in terms of objective fitness level and subjective pacing strategy. Therefore, in both the previous study and the present study, it was defenders who played the longest time on the field who had the lowest physical demands. Positional differences may also be related to the tactical roles and responsibilities of each position, and specific game scenarios. Forwards are supposed to create opportunities and score goals in the game, which requires of them to create space and quickly break the opponent's defensive line. Meanwhile for the midfielders, they are not only responsible for offensive actions but also for defensive ones, more specifically, responsibilities during offense to defense or defense to offense transitions. Hence, the midfielders are required to have more multi-directional movements for choosing the appropriate positions and directions. For defenders, their main responsibilities are marking the opponents and passively responding to the opponent players' actions and the changes of ball directions, which would happen in smaller area, hence, not much space for free running (Delves, Bahnisch, Ball, & Duthie, 2021; Polglaze, Dawson, Hiscock, & Peeling, 2015), and this might also be the reason why the majority of the short, explosive movements (IMA counts) of defenders in the current study were not significantly lower than those of the forwards and midfielders. These assumptions need to be confirmed by contextualised performance data (i.e., analysing the physical outputs and movement profile for each specific tactical scenario).

When comparing running intensity recorded in this study with other studies, the distance per minute for forwards was 130±5 m, which was lower than the 134±15 m of the Malaysian national team forwards (James, et al., 2021) and higher than the 123±17 m of the Olympic team forwards (McMahon & Kennedy, 2019). It is challenging to compare the HSRD data across studies because there is no standardised HSRD threshold. The commonly used HSRD thresholds in men's hockey were 15 kmh^{-1}, 15.5 kmh^{-1}, and 19 kmh^{-1} (Casamichana, Morencos, Romero-Moraleda, & Gabbett, 2018; Ihsan, et al., 2021; Lam, et al., 2021; McMahon & Kennedy, 2019; Morencos, et al., 2018; Sunderland & Edwards, 2017; White & MacFarlane, 2013). In the current study, 15 kmh^{-1} was chosen as the threshold for HSRD in order to facilitate comparison with recent studies that had similar methodologies. In comparison with a men's team competing in the Olympic Games reported by McMahon and Kennedy (2019), HSRD per minute in our study was lower for defenders (14.8±2.5 $mmin^{-1}$) than the 22.8±8.9 $mmin^{-1}$ for defenders on that team, and lower for midfielders (29.8±4.7 $mmin^{-1}$) than 36.1±6.1 $mmin^{-1}$ for midfielders on that team. HSRD per minute for forwards in the present study and previous study were slightly lower (33.5±3.9 $mmin^{-1}$ and 34.6±8.9 $mmin^{-1}$, respectively). The main reason why the high-speed running performance of the subjects in the present study was lower than that of the teams competing in the Olympic Games may be due to the level of competition and team ranking, as reported in previous research (Paul, Bradley, & Nassis, 2015). AccDec count per minute for each position in our study was much higher than the average of 71 matches over a two-year period reported by James et al. (2021); however, the high IMA count per minute findings were similar. This indicates that the acceleration and deceleration data derived from GPS technology (>2 ms^{-2}) and the high-intensity IMA data obtained from inertial sensor technology (>3.5 ms^{-1}) are essentially describing different types of physical demands, with the former being the ability to start and brake, and the latter being the ability to make explosive movements over small distances.

Differences among quarters

The results show that all running variables (total distance per minute, HSRD per minute, and RHIE per minute), as well as AccDec per minute, and player load per minute were significantly higher in quarter 1 than in the other three quarters. Total distance per minute and player load per minute were significantly higher in quarter 2 than in quarter 4. This suggests that under the current

FIH four-quarter format, the intensity of play for the teams in this study was highest in quarter 1, followed by a significant drop in quarter 2 and after an intermission, there was no further significant drop in quarter 3, but a further drop in overall running performance occurred in quarter 4 relative to quarter 2. The change in total distance per minute was consistent with previous reports, but not with the findings of previous studies in terms of HSRD per minute. The previous study by James et al. (2021) found that HSRD per minute reached its peak in quarters 1 and 4, which could be due to specific game scenarios such as the scoring situation in each quarter, substitution strategies, tactical strategies, etc. The study by Ihsan et al. (2021) suggested that players may intentionally conserve their effort during the game and run at high speed only when it matters most. It is therefore important to understand and consider the context on the field when interpreting the patterns of change in the variables over time, in addition to the natural effects of physiological fatigue. There were no significant differences between the four quarters in all IMA category variables, suggesting that the IMA counts are not sensitive to fatigue. In future studies, these can be further clarified if the game data is further segmented into smaller time intervals (i.e., 1-min intervals) and if the trend of IMA counts is analysed after each rotation or quarter break.

When looking at the movement profiles, results show that static duration% increased quarter by quarter (from 9.8±2.2% in quarter 1 to 17.2±4.5% in quarter 4). Linear running duration% dropped significantly from 17.7±1.7% in quarter 1 to 15.7±1.6% in quarter 2, recovered in quarter 3 after the halftime break (15±2.1%), and again dropped in quarter 4 to 13.6±1.5%. The pattern for non-linear dynamic movement duration% was similar to linear running duration%, dropping from 36.5±2.8% in quarter 1 to 30.3±3.6% in quarter 4. This suggests that the players were most active in quarter 1, with 54.2% of the time (linear running and non-linear dynamic movement combined) being spent doing meaningful running, acceleration and deceleration, while by quarter 4, only 43.9% of the time was spent doing active movements. This result suggests that movement profile analysis can also be used to flag fatigue status during a game and provide supporting information for substitution strategies. The current study revealed for the first time the movement profiles during a field hockey game. In a previous study on football, Szigeti et al. (2021) collected data from 34 international matches of a national team and reported 15.6% for static duration% during official games, 35.8% for walking, 20.8% for linear running, and 27.8% for non-linear dynamic movements. Comparing the results of the present study with football, it can be seen that field hockey game is similar to the football game in terms of the percentage of active, but within the active time, football games are having more time spent on linear running, while in field hockey games players spend more time on non-linear movements such as acceleration and deceleration, change of direction and other movements.

After the 2015 FIH rule change, only one study included heart rate data for the four-quarter format of men's field hockey games. However, each quarter of that study was 17.5 minutes in length rather than the FIH standard of 15 minutes used in the current study, and the study was conducted with college athletes, not professional athletes (Lam, et al., 2021). In that study, the relative mean heart rate values in the first to fourth quarters were 84.5±5.2%, 84.5±5.1%, 82.3±5.9%, and 82.4±6.0%, respectively, similar to the results of the present study (84.3±2.8%, 85.6±2.2%, 83.6±3.4%, and 83.6±2.9%, respectively), all being slightly higher in the first two quarters and slightly lower in the last two quarters. However, there was no significant difference. The previous study also reported the percentage of time with a heart rate >85% of the individual's maximal heart rate, which was 60.8%, 60.8%, 51.1%, and 51.0% from quarter 1 to quarter 4, respectively. The present study used >86% HR_{max} as a threshold and reported similar results (58.3%, 63.4%, 52.7%, and 52.2 from quarter 1 to quarter 4, respectively). In another previous study that was under the old 2-half rule, Lythe and Kilding (2011) reported similar results—the Avg. HR% in the 1st half was higher than the Avg. HR% in the 2nd half, but the difference was not significant.

As can be seen in the current study, >86% HR_{max} duration% was highest in quarter 2. Also, approximately 50-60% of the time in professional level men's field hockey game players are working at anaerobic threshold intensity under the current four-quarter rule. The $TRIMP_{mod}$ per minute also shows that the physiological demand was highest and statistically significant in the second quarter. The external physical load data from quarter 2 decreased in intensity, while an increase was observed in internal load (physiological response) compared to quarter 1; this suggests that players reach a state of fatigue in the second quarter and are unable to maintain a higher intensity of external physical load output, indicating that the coaches should focus more on quarter 2 in terms of the substitution strategies and make more frequent substitutions in the second quarter to ensure that players are fresh and can maintain external physical output at a high level.

The current study is not without limitations. When interpreting the data of the current study, there are several contexts to be considered. The participants were all from only one team and competed in one championship. Hence, some findings might not be representative for other teams with different playing philosophies, and at different competitive levels. Additionally, the team in the current study was the champion of the tournament and beat most of the opponents, therefore, the physical outputs might be impacted. Furthermore, there was no context of tactical considerations (i.e., rotations, ball possessions, etc.). It is recommended for the future studies to investigate further with multiple teams and embed the tactical contexts into the physical and physiological data to gain more specific demands for specific scenarios.

To conclude, defenders had the highest volume in terms of the absolute game demands due to their high playing minutes; however, they had the lowest game intensity compared with the other positions. This includes both physical outputs and physiological responses. Forwards had the highest linear running intensity, while midfielders were required to execute more multi-directional, non-linear movements. Defenders had lower demands in linear running intensity, but not lower in explosive, multi-directional movements. Heart rate data suggested that forwards and midfielders should focus more on lactate threshold and anaerobic threshold training compared to defenders. Nevertheless, none of the three positions, especially defenders, should neglect the maximal intensity training. Practitioners should take positional requirements into considerations when prescribing training loads. Quarter 1 was the most active quarter and players became fatigued in quarter 2. Movement profile variables and $TRIMP_{mod}$ per minute can be used in game to inform coaches of real-time physical condition of the players and assist with the decision-making in terms of substitutions.

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