



Monitoring Wellness, Training Load, and Running Performance During a Major International Female Field Hockey Tournament

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

Authors: Aideen McGuinness¹, Shane Malone^{1,2}, George Petrakos³, Kieran Collins¹

Affiliations: 1. Institute of Technology Tallaght, Tallaght, Dublin 24, Ireland. 2. The Tom Reilly Building, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, L3 2ET, UK 3. Glasgow Warriors, Scotstoun Stadium, 72 Danes Drive, Glasgow G14 9HD, United Kingdom

Running Title: Work-rate and physiological profile of female field hockey

Corresponding author:

Miss Aideen McGuinness

c/o Institute of Technology Tallaght, Tallaght, Dublin 24, Ireland

Email: mcguinnessaideen@gmail.com

Phone: +353831819630

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37 **ABSTRACT**

38

39 The aim of the current investigation was to quantify the physical and physiological
40 demands of elite international female field hockey match-play across halves of play. Thirty-
41 eight participants (24 ± 5 years; 173 ± 5 cm; 72 ± 5 kg) took part in nineteen competitive
42 matches during the 2014 – 2015 season. Participants were monitored with GPS technology
43 and heart rate monitors. Players were categorized based on three different playing positions.
44 Activity was categorized into total (m), high-speed running distance (m; $>16 \text{ km}\cdot\text{h}^{-1}$) and
45 relative distance ($\text{m}\cdot\text{min}^{-1}$) due to the use of rolling substitutions. Heart rate was classified
46 based on the percentage of players individual HR_{peak} determined via a Yo-Yo intermittent
47 recovery level 1 test. Players spent on average 44 ± 7 min in match-play. The total distance
48 covered was 5558 ± 527 m ($125 \pm 23 \text{ m}\cdot\text{min}^{-1}$) with 589 ± 160 m ($13 \pm 4 \text{ m}\cdot\text{min}^{-1}$) completed
49 at high-speed. Defenders covered a greater total distance compared to other positions of play
50 ($p \leq 0.001$). Midfield players covered a greater distance at high-speed ($p \leq 0.001$) with the
51 forwards having a higher relative distance ($p \leq 0.001$). The HR_{peak} of the players was 199 ± 1
52 $\text{b}\cdot\text{min}^{-1}$ with a mean exercise intensity of 86 ± 7.8 % of HR_{peak} . The time spent $>85\%$ HR_{peak}
53 decreased significantly across the halves ($p = 0.04$, $\eta^2 = 0.09$, Small). Defenders were found
54 to spend more time >85 % HR_{peak} when compared to forwards ($p \leq 0.001$). The current
55 investigation provides normative data that coaches should consider when constructing
56 training regimen.

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

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70 INTRODUCTION

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

82

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

96

97 Field hockey, like other team sports has a degree of positional variation with regard to
98 the physical demands (18,20,31,34). Research relating to female game is limited (14–
99 16,29,33). Jennings et al. (10) observed that with the roll-on roll-off nature of the game, the
100 high number of substitutions should be taken into consideration when interpreting the
101 differences between positional lines of play. The continuous substitution rule means that
102 players spend on average 48 minutes on the pitch during the whole 70 minute duration of
103 match play and typically cover 5541 ± 1144 m (16). Typically, defenders have been shown

104 to cover greater total distances (TD) (6170 – 6643 m) when contrasted against forwards
105 (4700 - 6154 m) and midfielders (5626 - 6931 m). Meanwhile, forwards have been observed
106 to complete higher relative distance (RD) of between 70 – 124 m·min⁻¹ when compared to the
107 defenders and midfield players (79 – 110 m·min⁻¹; 79 - 113 m·min⁻¹) (7,16,33). Vescovi and
108 Frayne (33) have suggested that differences in playing time can effect high-speed distance
109 (HSD), with Macutkiewicz and Sunderland (16) observing that forwards spent more time
110 performing high-intensity exercise (8 %) when compared to midfielders (6 %) and defenders
111 (5 %).

112

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

136

137 Research conducted on elite international female field hockey cohorts is limited
138 (16,23,33). Therefore, an updated examination of physical and physiological responses
139 during match-play is warranted to allow practitioners to construct training methodologies that
140 best replicate the current positional demand of international competition. Given the above,
141 the primary aim of the current investigation was to quantify the physical and physiological
142 demands of elite international female hockey players during competitive match-play.
143 Furthermore, we aimed to determine the position specific differences in physical and
144 physiological profiles across halves of play. It was hypothesized that defenders would cover
145 greater TD; midfielders would cover more high-speed distance (HSD) while the forwards
146 who spend the least amount of time in competitive match-play would be seen to have a
147 higher relative distance (RD) output. It was expected that female field hockey would be
148 played at a low to moderate intensity (7,18) with limited time > 85 % HR_{peak}.

149

150 **METHODS**

151

152 *Experimental approach to the problem*

153 The current observational study was designed to examine the physical and
154 physiological demands of elite international female field hockey players using portable GPS
155 technology (4-Hz, VXsport, Lower Hutt, New Zealand) and HR monitors (Polar Team 2,
156 Polar Electro Oy, Kempele, Finland) across halves of match-play. Prior to match-play data
157 collection, participants performed a Yo-Yo intermittent recovery test level 1 (Yo-YoIR1) to
158 identify each players speed threshold and heart rate max (HR_{max}). Thirty-eight elite
159 international female field hockey players were observed during nineteen competitive games
160 over the 2014 – 2015 international season. Across the observational period both test series
161 and International Hockey Federation ranked games were played against opponents with a
162 world ranking ranging from four to thirty-four. Players were categorized based on positional
163 line of play (defender, midfielder and forward). HR was recorded via short range radio
164 telemetry. Game data was only included if the player was to play a minimum of ten minutes
165 in both halves of competitive match-play. Research has shown that the maximum speed
166 capabilities of females to be lower than males, therefore it is recommended that female-
167 specific speed thresholds be established for the analysis of the physical demands (4).
168 Previous research has suggested that repeated bouts of high-speed during match-play is
169 associated with elevation in blood lactate accumulation (3,4). During the Yo-YoIR1 players

170 achieved maximum distances ranging between 1600 – 1920 m (17.5 – 18.5 km·h⁻¹). Given
171 that high-speed should be above the onset of blood lactate accumulation, generic high-speed
172 thresholds were set at 90 % which equated to 16 km·h⁻¹. All competitive matches took place
173 between 14.00 and 20.00 hours. Prior to match-play (24 - 48 hours) players were requested to
174 abstain from strenuous physical activity and were advised to maintain their normal diet, with
175 special emphasis being placed on the intake of fluids and carbohydrates.

176 177 *Subjects*

178 Thirty-eight elite international female field hockey outfield players (24 ± 5 years; 163
179 ± 5 cm; 64 ± 5 kg) participated in the current study. Players were selected as they were
180 members of the country's national hockey squad that season, therefore were deemed the best
181 players in the country at the time of data collection. After ethical approval, participants
182 attended an information evening where they were briefed about the purpose, benefits, and
183 procedures of the study. Written informed consent and medical declaration were obtained
184 from participants in line with the procedures set by the local institution's research ethics
185 committee

186 187 *Physical Demands*

188 The participants wore an individual GPS unit (VXsport, Lower Hutt, New Zealand,
189 Issue: 330a, Firmware: 3.26.7.0) sampling at 4-Hz and containing a triaxial accelerometer
190 and magnetometers in a total of 30 games. The GPS unit (mass: 76 g; 48 mm x 20 mm x 87
191 mm) was encased within a protective harness between the player's shoulder blades in the
192 upper thoracic-spine region this ensured that players' range of movement in the upper limbs
193 and torso was not restricted. Prior to the GPS being inserted into the harness, the devices
194 were turned on and a satellite connection was established fifteen minutes before the warm up.
195 The GPS data was extracted from each device using proprietary software (VXsport View,
196 New Zealand). Given the use of rolling substitutes the time each participant spent in match-
197 play was noted to accurately track the players physical and physiological demands for a given
198 game. The data was analyzed retrospectively and exported to Microsoft Excel (Microsoft,
199 Redmond, USA) this allowed for further in-depth analysis. Physical demands were classified
200 based on distance covered across four zones adapted from those recently used in female field
201 hockey (33). Zone 1 (0-7.9 km·h⁻¹), zone 2 (8-15.9 km·h⁻¹), zone 3 (16-19.9 km·h⁻¹) and zone
202 4 (> 20 km·h⁻¹). Other variables of interest included relative total distance (RTD) (m·min⁻¹);

203 relative high-speed distance (RHSD) ($\text{m}\cdot\text{min}^{-1}$; $>16 \text{ km}\cdot\text{h}^{-1}$). The coefficient of variation (CV
204 %) of the GPS unit during intermittent exercise has previously been reported as 1.0 – 8.0 %.
205 (17)

206

207 *Physiological Demands*

208 Physiological demands during match-play were assessed based on HR analysis, which
209 was recorded every 5 seconds using a telemetric device (Polar Team Sport System 2; Polar
210 Electro Oy, Kempele, Finland). The highest HR value reached during the Yo-YoIR1 was
211 taken as the players peak heart rate (HR_{peak}). The test selected was part of the team's regular
212 performance testing regime and all players were familiar with the methods. Participants were
213 provided with a heart rate monitor (Polar Team 2, Polar Electro Oy, Kempele, Finland),
214 which was secured with a chest strap. Players exercise intensity was spilt into four zones
215 adapted from those recently used in female field sports (26,29,30). Zone 1 ($< 69 \% \text{ HR}_{\text{peak}}$),
216 zone 2 ($70 - 84 \% \text{ HR}_{\text{peak}}$), zone 3 ($85 - 89 \% \text{ HR}_{\text{peak}}$) and zone 4 ($> 90 \% \text{ HR}_{\text{peak}}$). Other
217 variables of interest included HR_{peak} and mean heart rate (HR_{mean}). The HR_{peak} was
218 subsequently used during competitive match-play with values calculated as a percentage of
219 this figure. The HR_{mean} for each match were recorded and expressed as a percentage of
220 individual HR_{peak} to provide an indication of the overall intensity of the match in relation to
221 the HR_{mean} and HR_{peak} during match-play. Data was downloaded and analyzed retrospectively
222 (Polar Precision Performance v4.03.043) and exported to a customized excel file. The CV %
223 of HR response during intermittent exercise has previously been reported as 1.3 – 4.8 %
224 (12,28).

225

226 *Statistical Analysis*

227 Data is presented as means \pm standard deviation with 95 % confidence intervals (95 %
228 CIs) and effect size, partial Eta-squared (η^2). Any data that was not normally distributed was
229 removed from data analysis. A multivariate analysis of variance (MANOVA) was used to
230 examine the difference between positional groups (3) and halves of play (2). The dependent
231 variables across the range of analysis were, TD (m); HSD (m ; $>16 \text{ km}\cdot\text{h}^{-1}$), RTD ($\text{m}\cdot\text{min}^{-1}$);
232 RHSD ($\text{m}\cdot\text{min}^{-1}$; $>16 \text{ km}\cdot\text{h}^{-1}$), average HR_{max} and percentage HR_{max} with playing position and
233 match-play periods (e.g, first and second half) independent variables. Standardized effect
234 sizes (ES) were reported as partial eta squared (η^2) with effects defined as small 0.01 – 0.08,

235 medium 0.09 – 0.24 and large > 0.25. Statistical significance was accepted at $p \leq 0.05$. SPSS
236 Version 22.0 (IBM Corporation, New York, USA) software were used to analyze the data.

237

238 RESULTS

239

240 *Physical Demands*

241 The time spent in competitive match-play was 44 ± 7 min (95 % CI: 36 – 52 min)
242 which accounted for 63 % of game time. The time on field remained the same across the
243 halves regardless of position (22 ± 4 min). The physical demands observed during match-
244 play are presented in Table 1. The TD covered regardless of position was 5558 ± 527 m (95
245 % CI: 5353 – 5740 m). A non-significant difference in TD was observed ($p = 0.6$; $\eta^2 = 0.01$;
246 Small) between the first (2820 ± 266 m; 95 % CI: 1971 – 3455 m) and second half ($2705 \pm$
247 300 m; 95 % CI: 1992 – 3351 m). The RTD observed was 125 ± 23 m·min⁻¹ (95 % CI: 125 –
248 127 m·min⁻¹) regardless of position. The RTD covered by players decreased between the first
249 (128 ± 10 m·min⁻¹) and second (123 ± 13 m·min⁻¹) halves, although this difference was non-
250 significant ($p = 0.5$; $\eta^2 = 0.4$; Large) (Figure 1). The RHSD was 13 ± 4 m·min⁻¹ (95 % CI: 5 –
251 20 m·min⁻¹) irrespective of position, with no differences observed ($p = 0.5$; $\eta^2 = 0.4$; Large)
252 across the halves (14 ± 4 m·min⁻¹, 95 % CI: 6 – 20 m·min⁻¹; 13 ± 5 m·min⁻¹, 95 % CI: 5 – 29
253 m·min⁻¹) (Figure 2).

254

255 **INSERT TABLE 1 NEAR HERE**

256

257 *Positional Physical Demands*

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

268 When RTD was considered (Figure 1) the forwards ($131 \pm 10 \text{ m}\cdot\text{min}^{-1}$, 95 % CI: 116
269 $- 146 \text{ m}\cdot\text{min}^{-1}$) and midfielders ($129 \pm 5 \text{ m}\cdot\text{min}^{-1}$, 95 % CI: 121 $- 138 \text{ m}\cdot\text{min}^{-1}$) covered higher
270 RTD when compared to defenders ($114 \pm 7 \text{ m}\cdot\text{min}^{-1}$; 95 % CI: 103 $- 123 \text{ m}\cdot\text{min}^{-1}$)
271 respectively ($p = 0.001$; $\eta^2 = 0.5$; Large). Similarly, significant positional differences were
272 observed for the RHSD ($p = 0.001$, $\eta^2 = 0.3$, Large) with midfielders ($16 \pm 3 \text{ m}\cdot\text{min}^{-1}$, 95 %
273 CI: 12 $- 18 \text{ m}\cdot\text{min}^{-1}$) and forwards ($15 \pm 5 \text{ m}\cdot\text{min}^{-1}$, 95 % CI: 9 $- 17 \text{ m}\cdot\text{min}^{-1}$) covering a
274 RHSD ($>16 \text{ km}\cdot\text{h}^{-1}$) than defenders ($10 \pm 2 \text{ m}\cdot\text{min}^{-1}$, 95 % CI: 6 $- 22 \text{ m}\cdot\text{min}^{-1}$) during match-
275 play ($p = 0.001$) (Figure 2).

276

277 *Physiological Demands*

278 The HR_{peak} during match play was $199 \pm 1 \text{ b}\cdot\text{min}^{-1}$ with the HR_{mean} of $171 \pm 1 \text{ b}\cdot\text{min}^{-1}$,
279 reflective of an average exercise intensity (Table 2) regardless of position of $86 \pm 8 \%$ HR_{peak}
280 (95 % CI: 82 $- 91\%$ HR_{peak}). HR increased from $85 \pm 11 \%$ HR_{peak} (95 % CI: 82 $- 90\%$
281 HR_{peak}) to $87 \pm 2 \%$ HR_{peak} (95 % CI: 84 $- 91\%$ HR_{max}) across the halves, however this
282 variation was non-significant ($p = 0.4$; $\eta^2 = 0.02$; Small). The HR_{peak} during competitive
283 match-play was $96 \pm 4 \%$ HR_{peak} (95 % CI: 92 $- 98\%$ HR_{peak}), (Table 2). Players spent on
284 average $71 \pm 8 \%$ of competitive match-play engaged in exercise $> 85 \%$ HR_{peak} . The time
285 spent $> 85 \%$ HR_{peak} decreased significantly between the first ($16 \pm 3 \text{ min}$) and second halves
286 ($15 \pm 3 \text{ min}$) ($p = 0.04$; $\eta^2 = 0.09$; Medium) (Table 2).

287

288 **INSERT TABLE 2 NEAR HERE**

289

290 *Positional Physiological Demands*

291 No significant difference was observed in HR_{mean} when considered, relative to the
292 HR_{peak} ($p = 0.4$; $\eta^2 = 0.04$; Small) during match-play. Specifically, the HR_{peak} across positions
293 were as follows: defenders $86 \pm 2 \%$ HR_{peak} (95 % CI: 85 $- 91\%$ HR_{peak}), midfielders 87 ± 2
294 $\%$ HR_{peak} (95 % CI: 82 $- 89\%$ HR_{peak}) and forwards $85 \pm 12 \%$ HR_{peak} (95 % CI: 82 $- 90\%$
295 HR_{peak}). When HR_{peak} during match play was considered non-significant differences across
296 positions were observed ($p = 0.36$; $\eta^2 = 0.05$; Small). Specifically, defenders $96 \pm 1 \%$ HR_{peak}
297 (95 % CI: 94 $- 97 \%$ HR_{peak}), midfielders $96 \pm 6 \%$ HR_{peak} (95 % CI: 93 $- 97 \%$ HR_{peak}),
298 forwards $95 \pm 1 \%$ HR_{peak} (95 % CI: 92 $- 98 \%$ HR_{peak}). When time spent $> 85 \%$ HR_{peak} was
299 considered, significant differences were found across the positions ($p = 0.001$; $\eta^2 = 0.22$;
300 Medium). Defenders ($35 \pm 3 \text{ min}$; 95 % CI: 31 $- 41 \text{ min}$) were shown to spend a significantly

301 greater time > 85 % HR_{peak} than the forwards (29 ± 3 min; 95 % CI: 22 -34 min) and
302 midfielders (32 ± 7 min; 95 % CI: 24 – 45 min) (p = 0.001; η² = 0.22; Medium) (Figure 3).

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307 **DISCUSSION**

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

318

319 Our data shows that elite female field hockey players regardless of position spent 44 ±
320 7 min in competitive match-play. Players were shown to cover a TD of 5540 ± 521 m (126 ±
321 23 m·min⁻¹), with 589 ± 160 (13 ± 9 m·min⁻¹) covered at HSD regardless of playing position.
322 The observed mean playing time of 44 ± 7 min agrees with that previously reported by
323 Macutkiewicz and Sunderland (16) of 48 ± 4 min. However, these observations are lower
324 than those previously reported (33) (62.5 ± 12.8 min). Indeed, the analysis conducted by
325 Vescovi and Franye was completed on collegiate athletes, which may explain the discrepancy
326 observed. The TD covered during match-play was similar to that reported by Macutkiewicz
327 and Sunderland (16) (5541 ± 1144 m) but lower than that reported by Vescovi and Franye
328 (33) (6461 ± 1294 m). The RTD of 103 m·min⁻¹ was less than that reported in the current
329 study which suggest that elite field hockey players cover distance at increased relative
330 intensity when compare to collegiate athletes. Furthermore, the relative data reported in the
331 current study is in agreement with previous analyses on female hockey cohorts (16).

332

333

****INSERT FIGURE 1 NEAR HERE****

334

335 Previous studies examining team sports have shown that a team's success can be
336 related to time in possession of the ball and the ability to cover HSD (1,8). The results of the
337 current study suggested that regardless of position, players covered 589 ± 160 m reflective of
338 13 ± 9 m·min⁻¹ at HS (m; >16 km·h⁻¹). Vescovi and Franye (27) recently reported a slightly
339 higher HSD (m; >16 km·h⁻¹) during match-play of 631 ± 173 m (10 m·min⁻¹). Anderson et al.
340 (1) showed that female athletes performed more HSD during international match-play than
341 during domestic match-play respectively. Although the current study suggest that elite
342 players cover less HSD during match-play they were shown to cover more RHSD then that
343 previously reported for domestic players (1). However, Macutkiewicz and Sunderland (16)
344 reported the average HSD (m; >15.1 km·h⁻¹) covered by players was 852 ± 268 m (17.8 ± 67
345 m·min⁻¹). However, differences in selected speed thresholds across research make it hard to
346 compare results. The differences in RTD and RHSD outputs may be reflective of the
347 influence that the rolling substitution rule has on the game. The observed data may inform
348 coaches of potential strategies to maximize this rule by employing a specific rolling substitute
349 policy based on GPS and HR data of players. Indeed, coaches may decide to make
350 substitutions based on reductions in HSD and RHSD given that these variables have been
351 previously linked to technical outputs during match-play (8).

352

353 ** INSERT FIGURE 2 NEAR HERE **

354

355

356 Monitoring HR responses during match-play provides an indication of the internal
357 physiological load during game play actions (32). The HR_{peak} of the players was 199 ± 1
358 b·min⁻¹ with the HR during match-play of 171 ± 1 b·min⁻¹ reflective of an average exercise
359 intensity regardless of position of 86 ± 8 % HR_{peak}. During competitive match-play players
360 had a HR_{peak} of 96 ± 3.5 %. Sell and Ledesma (29) examined HR responses in NCAA
361 division I colligate female hockey players and reported HR_{peak} responses of 94.6 ± 3.3 %.
362 Regardless of position Sell and Ledesma (29) reported the HR_{peak} of international female
363 hockey players was 203 ± 7 b·min⁻¹ which is higher than previously observed by MacLeod et
364 al. (15) (190 ± 9 b·min⁻¹) and our current observations. The time spent > 85 % HR_{peak} has
365 been previously shown to be associated with improvements in aerobic capacity while also
366 being linked to an improved physical activity profile during match play (9,23). Therefore, it

367 is important for coaches to monitor the time spent $> 85\%$ HR_{peak} to best ensure players attain
368 these intensities during training, this will ultimately best equip them to compete during
369 match-play. The players in the current investigation spent on average 31 min $> 85\%$ HR_{peak}
370 suggesting that a high percentage of match-play is played at high-intensity.

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** INSERT FIGURE 3 NEAR HERE **

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

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

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

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INSERT FIGURE 4 NEAR HERE

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

The current study agrees with the previous findings of Sell and Ledesma (29) and Macutkiewicz and Sunderland (16) that reported no differences in HR_{mean} and HR_{peak} across positional lines of play within elite female hockey cohorts. However, positional differences were observed regarding time spent at different levels of intensity, Sell and Ledesma (29) suggested that the forwards spent more time at higher percentages of HR_{peak} . In contrast to the above findings our observations show that defenders spend more time $>85\% \text{ HR}_{\text{peak}}$. Our results are in agreement with Macutkiewicz and Sunderland (16) who suggested that although the forwards performed more moderate - high intensity exercise they were rewarded with more time to recover due to the roll on roll off substitution rule resulting in defenders having more time spent at higher percentages of HR_{peak} . The results of this study need to be

435 considered within the context of the study's limitations. Firstly, with no technical data it is
436 very difficult to assess the efficiency of players' physical activity. Additionally, although
437 acceptable validity and accuracy was reported for the specific GPS units used within the
438 current study, it should be noted that previous research has questioned the accuracy of GPS
439 for the measurement of high-speed movement (10). Finally, each player is biologically
440 different in both stature and physical capacity. With this in mind the authors advocate the
441 development of individualised player specific running thresholds for female hockey players
442 (4). The results of this study need to be interpreted within the context of the studies
443 limitations. No measure of match dynamics (win or loss) and tactical styles of play were
444 considered. Recently, studies have shown there to be match to match variation in other field
445 sports (5,25). Future studies should report the typical match-to-match variation of GPS
446 variables with elite female field hockey. To date no studies have examined the physical
447 activity profiles of elite female field hockey players during a condensed high intensity period
448 with quick turnarounds such as an international tournament environment. Therefore, we
449 recommend that the changes in physical activity be reported for these highly demanding
450 periods. Finally, we suggest that future research should consider the current advancements in
451 field sports and the known energetic cost of accelerated movements. Therefore, an analysis of
452 the metabolic power profile of elite international female hockey is warranted to improve
453 coaches understanding of the energetic cost associated with competitive match-play.

454

455 **PRACTICAL APPLICATIONS**

456

457 The current study provides an insight into the physical and physiological demands of
458 elite international female hockey across both positions and halves of play. During
459 competitive match-play players are likely to cover 61 % of their TD $> 8 \text{ km}\cdot\text{h}^{-1}$ irrespective of
460 position. Our results showed that defenders spent more time in match-play and covered more
461 TD when compared to other positions. Midfielders were found to cover on average 68 % of
462 their TD distance $> 8 \text{ km}\cdot\text{h}^{-1}$ which was more than defenders (9 %) and the forwards (2%).
463 When high-speed was considered, midfielders covered over 15% of their TD $> 16 \text{ km}\cdot\text{h}^{-1}$
464 which was similar to forwards (14 %) but significantly greater than defenders (10%). The
465 results highlight the need for coaches to consider the positional profile of match-play prior to
466 planning training regimen in order to best replicate players' specific match-play physical
467 activity profile. For example, midfield players should be placed into drills that allow them to
468 cover more HSD while forwards should be placed into more intense drills that allow them to

469 cover more distance in a shortened period in order to increase their RTD to that similar of
470 match-play. Previous research has shown a strong linear association between HR and volume
471 of oxygen consumption, which can then be used to determine the level of intensity and the
472 physiological demands in competitive match-play (6). Therefore, with the use of HR
473 monitors the monitoring time spent at different zones and average HR can be used to
474 effectively reflect the aerobic metabolic demands of competitive match-play (6). Our data
475 therefore confirm that competitive match-play is mainly aerobic in nature. At set time points
476 within a periodised plan coaches should aim to have specific periods of training drills >85 %
477 HR_{peak}. We observed that defenders were the only position to have a notable decrement in
478 running performance across halves of play. However, in order to reduce the likelihood of
479 these reductions in physical activity it may be suggested that half-time nutritional strategies,
480 in addition to a half-time re-warm up strategy be implemented by coaches. Overall the
481 current study provides normative data on the physical activity and physiological profiles of
482 elite international female hockey players. From these findings, it may be suggested that
483 coaches use these data to implement position specific training drills in order to best replicate
484 the demands of each position. Furthermore the data will aid coaches in developing specific
485 player interchange protocols during match environments.

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595 **TABLE AND FIGURE CAPTIONS**

596

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

600

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

603

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

607

608 * signifies the difference between the first and second halves ($p = 0.04$; $\eta^2 = 0.09$; Medium).

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

611

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

614

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

618

619 **Figure 2.** The RHSD (relative high-speed distance) $\text{m}\cdot\text{h}^{-1}$ ($\text{m}\cdot\text{min}^{-1}$) covered across
620 all three positions during competitive match-play. All data is presented as mean \pm SD.

621

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

625

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

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

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

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

1 **Table and Figures**

2 **Table 1.**

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

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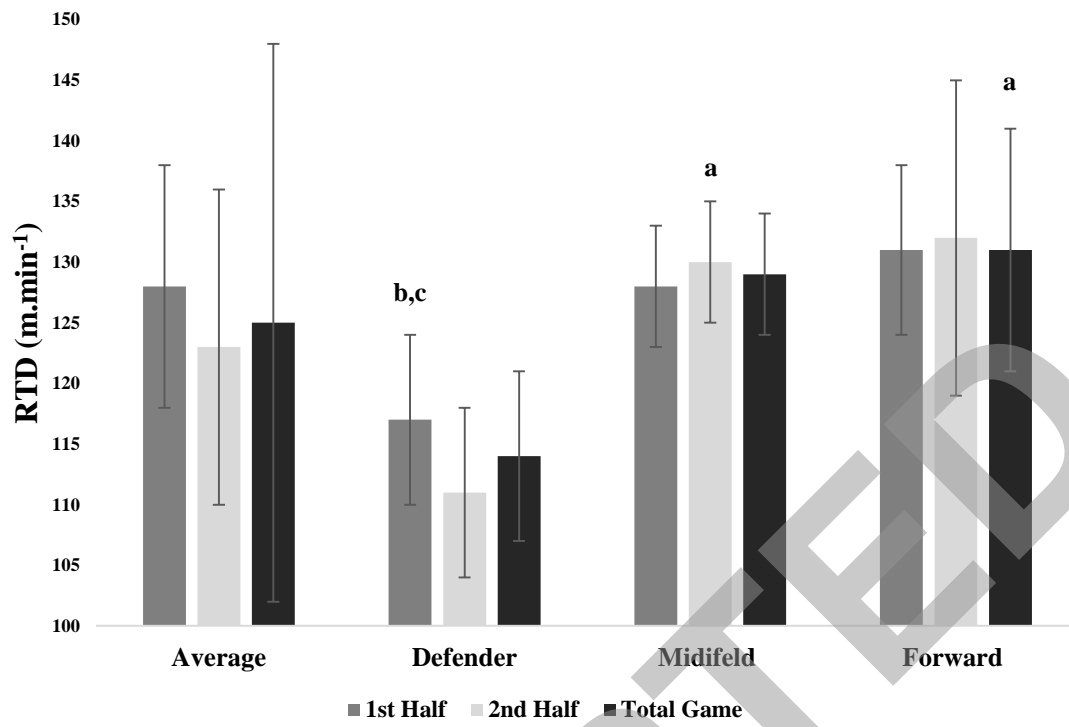
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5 **Table 2.**

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

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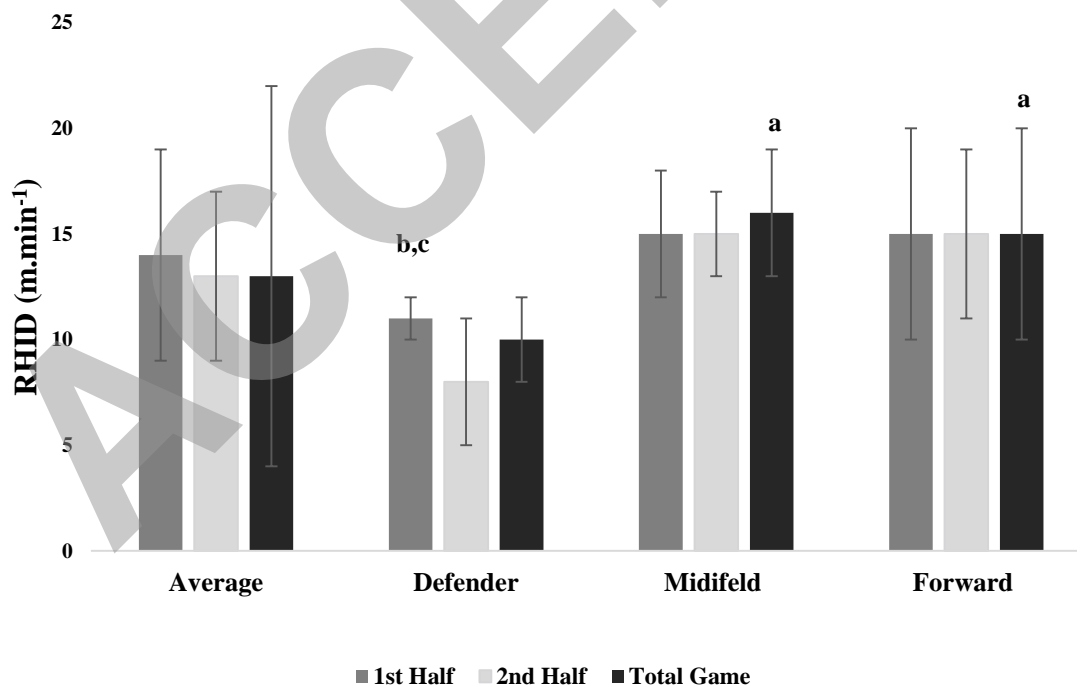
1 **Figure 1.**



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4 **Figure 2.**

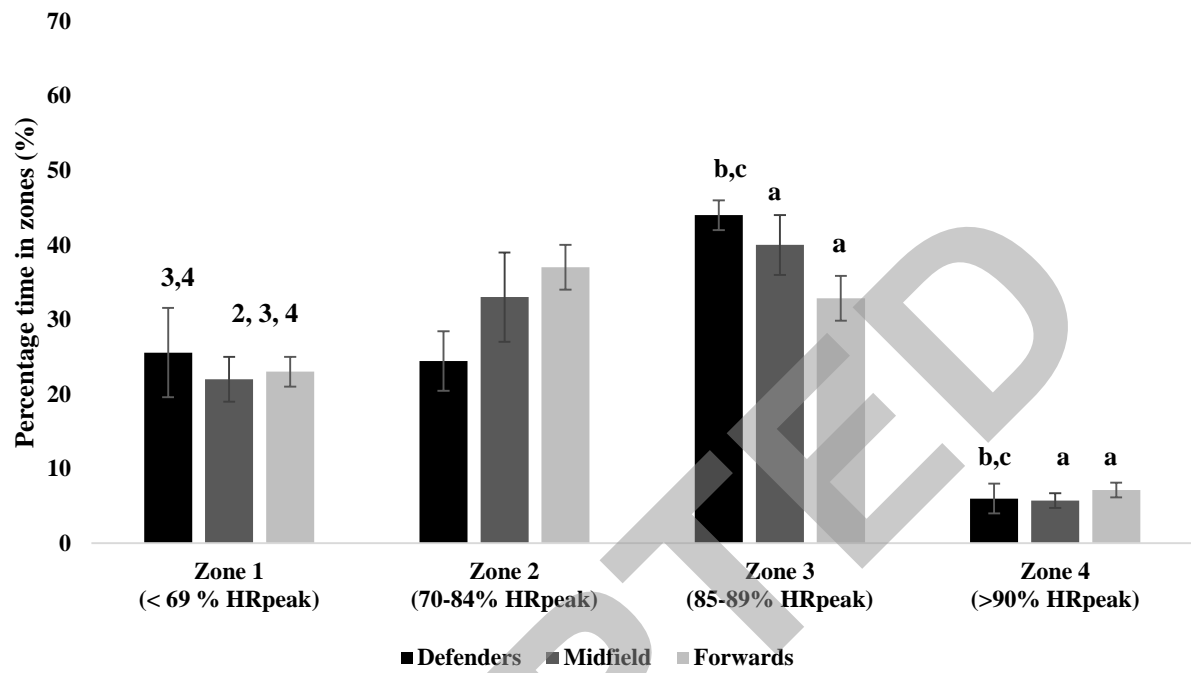


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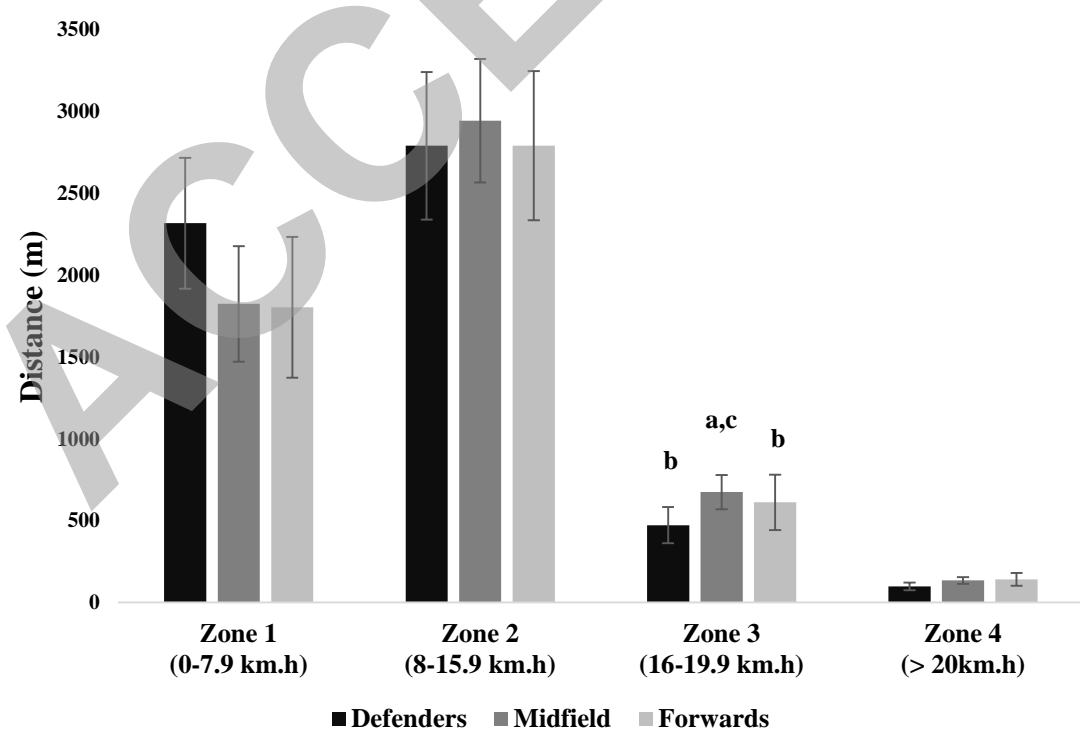
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1 **Figure 3.**



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Figure 4.



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