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Article in *The Journal of Strength and Conditioning Research* · July 2017

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

5

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22

23 **Abstract Word Count:** 250 Words

24

25 **Word Count:** 3500 Words

26

27 **Number of tables and figures:** 2 Tables; 3 Figures

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36 **ABSTRACT**

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

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

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69 **INTRODUCTION**

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

81

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

95

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

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

110

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

133

134 Research conducted on elite international female field hockey cohorts is limited
135 (16,23,33). Therefore, an updated examination of physical and physiological responses during
136 match-play is warranted to allow practitioners to construct training methodologies that best

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

146

147 **METHODS**

148

149 *Experimental approach to the problem*

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

170 to match-play (24 - 48 hours) players were requested to abstain from strenuous physical activity
171 and were advised to maintain their normal diet, with special emphasis being placed on the
172 intake of fluids and carbohydrates.

173

174 *Subjects*

175 Thirty-eight elite international female field hockey outfield players (24 ± 5 years; 163
176 ± 5 cm; 64 ± 5 kg) participated in the current study. Players were selected as they were members
177 of the country's national hockey squad that season, therefore were deemed the best players in
178 the country at the time of data collection. After ethical approval, participants attended an
179 information evening where they were briefed about the purpose, benefits, and procedures of
180 the study. Written informed consent and medical declaration were obtained from participants
181 in line with the procedures set by the local institution's research ethics committee

182

183 *Physical Demands*

184 The participants wore an individual GPS unit (VXsport, Lower Hutt, New Zealand,
185 Issue: 330a, Firmware: 3.26.7.0) sampling at 4-Hz and containing a triaxial accelerometer and
186 magnetometers in a total of 30 games. The GPS unit (mass: 76 g; 48 mm x 20 mm x 87 mm)
187 was encased within a protective harness between the player's shoulder blades in the upper
188 thoracic-spine region this ensured that players' range of movement in the upper limbs and torso
189 was not restricted. Prior to the GPS being inserted into the harness, the devices were turned on
190 and a satellite connection was established fifteen minutes before the warm up. The GPS data
191 was extracted from each device using proprietary software (VXsport View, New Zealand).
192 Given the use of rolling substitutes the time each participant spent in match-play was noted to
193 accurately track the players physical and physiological demands for a given game. The data
194 was analyzed retrospectively and exported to Microsoft Excel (Microsoft, Redmond, USA) this
195 allowed for further in-depth analysis. Physical demands were classified based on distance
196 covered across four zones adapted from those recently used in female field hockey (33). Zone
197 1 ($0-7.9 \text{ km}\cdot\text{h}^{-1}$), zone 2 ($8-15.9 \text{ km}\cdot\text{h}^{-1}$), zone 3 ($16-19.9 \text{ km}\cdot\text{h}^{-1}$) and zone 4 ($> 20 \text{ km}\cdot\text{h}^{-1}$).
198 Other variables of interest included relative total distance (RTD) ($\text{m}\cdot\text{min}^{-1}$); relative high-speed
199 distance (RHSD) ($\text{m}\cdot\text{min}^{-1}$; $>16 \text{ km}\cdot\text{h}^{-1}$). The coefficient of variation (CV %) of the GPS unit
200 during intermittent exercise has previously been reported as 1.0 – 8.0 %. (17)

201

202 *Physiological Demands*

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

219

220 *Statistical Analysis*

221 Data is presented as means \pm standard deviation with 95 $\%$ confidence intervals (95 $\%$
222 CIs) and effect size, partial Eta-squared (η^2). Any data that was not normally distributed was
223 removed from data analysis. A multivariate analysis of variance (MANOVA) was used to
224 examine the difference between positional groups (3) and halves of play (2). The dependent
225 variables across the range of analysis were, TD (m); HSD (m; $>16\text{ km}\cdot\text{h}^{-1}$), RTD ($\text{m}\cdot\text{min}^{-1}$);
226 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
227 match-play periods (e.g, first and second half) independent variables. Standardized effect sizes
228 (ES) were reported as partial eta squared (η^2) with effects defined as small 0.01 – 0.08, medium
229 0.09 – 0.24 and large > 0.25 . Statistical significance was accepted at $p \leq 0.05$. SPSS Version
230 22.0 (IBM Corporation, New York, USA) software were used to analyze the data.

231

232 **RESULTS**

233

234 *Physical Demands*

235 The time spent in competitive match-play was 44 ± 7 min (95 % CI: 36 – 52 min) which
236 accounted for 63 % of game time. The time on field remained the same across the halves
237 regardless of position (22 ± 4 min). The physical demands observed during match-play are
238 presented in Table 1. The TD covered regardless of position was 5558 ± 527 m (95 % CI: 5353
239 – 5740 m). A non-significant difference in TD was observed ($p = 0.6$; $\eta^2 = 0.01$; Small) between
240 the first (2820 ± 266 m; 95 % CI: 1971 – 3455 m) and second half (2705 ± 300 m; 95 % CI:
241 1992 – 3351 m). The RTD observed was 125 ± 23 m·min⁻¹ (95 % CI: 125 – 127 m·min⁻¹)
242 regardless of position. The RTD covered by players decreased between the first (128 ± 10
243 m·min⁻¹) and second (123 ± 13 m·min⁻¹) halves, although this difference was non-significant
244 ($p = 0.5$; $\eta^2 = 0.4$; Large) (Figure 1). The RHSD was 13 ± 4 m·min⁻¹ (95 % CI: 5 – 20 m·min⁻¹)
245 irrespective of position, with no differences observed ($p = 0.5$; $\eta^2 = 0.4$; Large) across the
246 halves (14 ± 4 m·min⁻¹, 95 % CI: 6 – 20 m·min⁻¹; 13 ± 5 m·min⁻¹, 95 % CI: 5 – 29 m·min⁻¹)
247 (Figure 2).

248

249 **INSERT TABLE 1 NEAR HERE**

250

251 *Positional Physical Demands*

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

262 When RTD was considered (Figure 1) the forwards (131 ± 10 m·min⁻¹, 95 % CI: 116 –
263 146 m·min⁻¹) and midfielders (129 ± 5 m·min⁻¹, 95 % CI: 121 – 138 m·min⁻¹) covered higher RTD
264 when compared to defenders (114 ± 7 m·min⁻¹; 95 % CI: 103 – 123 m·min⁻¹) respectively ($p =$
265 0.001 ; $\eta^2 = 0.5$; Large). Similarly, significant positional differences were observed for the
266 RHSD ($p = 0.001$, $\eta^2 = 0.3$, Large) with midfielders (16 ± 3 m·min⁻¹, 95 % CI: 12 – 18 m·min⁻¹)

267 ¹) and forwards ($15 \pm 5 \text{ m}\cdot\text{min}^{-1}$, 95 % CI: 9 – 17 $\text{m}\cdot\text{min}^{-1}$) covering a RHSD ($>16 \text{ km}\cdot\text{h}^{-1}$) than
268 defenders ($10 \pm 2 \text{ m}\cdot\text{min}^{-1}$, 95 % CI: 6 – 22 $\text{m}\cdot\text{min}^{-1}$) during match-play ($p = 0.001$) (Figure 2).

269

270 *Physiological Demands*

271 The HR_{peak} during match play was $199 \pm 1 \text{ b}\cdot\text{min}^{-1}$ with the HR_{mean} of $171 \pm 1 \text{ b}\cdot\text{min}^{-1}$,
272 reflective of an average exercise intensity (Table 2) regardless of position of $86 \pm 8 \%$ HR_{peak}
273 (95 % CI: 82 – 91% HR_{peak}). HR increased from $85 \pm 11 \%$ HR_{peak} (95 % CI: 82 – 90% HR_{peak})
274 to $87 \pm 2 \%$ HR_{peak} (95 % CI: 84 – 91% HR_{max}) across the halves, however this variation was
275 non-significant ($p = 0.4$; $\eta^2 = 0.02$; Small). The HR_{peak} during competitive match-play was 96
276 $\pm 4 \%$ HR_{peak} (95 % CI: 92 - 98% HR_{peak}), (Table 2). Players spent on average $71 \pm 8 \%$ of
277 competitive match-play engaged in exercise $> 85 \%$ HR_{peak} . The time spent $> 85 \%$ HR_{peak}
278 decreased significantly between the first ($16 \pm 3 \text{ min}$) and second halves ($15 \pm 3 \text{ min}$) ($p = 0.04$;
279 $\eta^2 = 0.09$; Medium) (Table 2).

280

281 **INSERT TABLE 2 NEAR HERE**

282

283 *Positional Physiological Demands*

284 No significant difference was observed in HR_{mean} when considered, relative to the
285 HR_{peak} ($p = 0.4$; $\eta^2 = 0.04$; Small) during match-play. Specifically, the HR_{peak} across positions
286 were as follows: defenders $86 \pm 2 \%$ HR_{peak} (95 % CI: 85 - 91% HR_{peak}), midfielders $87 \pm 2 \%$
287 HR_{peak} (95 % CI: 82 - 89% HR_{peak}) and forwards $85 \pm 12 \%$ HR_{peak} (95 % CI: 82 - 90% HR_{peak}).
288 When HR_{peak} during match play was considered non-significant differences across positions
289 were observed ($p = 0.36$; $\eta^2 = 0.05$; Small). Specifically, defenders $96 \pm 1 \%$ HR_{peak} (95 % CI:
290 94 – 97 % HR_{peak}), midfielders $96 \pm 6 \%$ HR_{peak} (95 % CI: 93 – 97 % HR_{peak}), forwards 95 ± 1
291 % HR_{peak} (95 % CI: 92 – 98 % HR_{peak}). When time spent $> 85 \%$ HR_{peak} was considered,
292 significant differences were found across the positions ($p = 0.001$; $\eta^2 = 0.22$; Medium).
293 Defenders ($35 \pm 3 \text{ min}$; 95 % CI: 31 – 41 min) were shown to spent a significantly greater time
294 $> 85 \%$ HR_{peak} than the forwards ($29 \pm 3 \text{ min}$; 95 % CI: 22 -34 min) and midfielders (32 ± 7
295 min; 95 % CI: 24 – 45 min) ($p = 0.001$; $\eta^2 = 0.22$; Medium) (Figure 3).

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298

299

300 DISCUSSION

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

311

312 Our data shows that elite female field hockey players regardless of position spent $44 \pm$
313 7 min in competitive match-play. Players were shown to cover a TD of 5540 ± 521 m ($126 \pm$
314 23 m·min⁻¹), with 589 ± 160 (13 ± 9 m·min⁻¹) covered at HSD regardless of playing position.
315 The observed mean playing time of 44 ± 7 min agrees with that previously reported by
316 Macutkiewicz and Sunderland (16) of 48 ± 4 min. However, these observations are lower than
317 those previously reported (33) (62.5 ± 12.8 min). Indeed, the analysis conducted by Vescovi
318 and Franye was completed on collegiate athletes, which may explain the discrepancy observed.
319 The TD covered during match-play was similar to that reported by Macutkiewicz and
320 Sunderland (16) (5541 ± 1144 m) but lower than that reported by Vescovi and Franye (33)
321 (6461 ± 1294 m). The RTD of 103 m·min⁻¹ was less than that reported in the current study
322 which suggest that elite field hockey players cover distance at increased relative intensity when
323 compare to collegiate athletes. Furthermore, the relative data reported in the current study is in
324 agreement with previous analyses on female hockey cohorts (16).

325

326 **INSERT FIGURE 1 NEAR HERE**

327

328 Previous studies examining team sports have shown that a team's success can be related
329 to time in possession of the ball and the ability to cover HSD (1,8). The results of the current
330 study suggested that regardless of position, players covered 589 ± 160 m reflective of 13 ± 9
331 m·min⁻¹ at HS (m; >16 km·h⁻¹). Vescovi and Franye (27) recently reported a slightly higher
332 HSD (m; >16 km·h⁻¹) during match-play of 631 ± 173 m (10 m·min⁻¹). Anderson et al. (1)

333 showed that female athletes performed more HSD during international match-play than during
334 domestic match-play respectively. Although the current study suggest that elite players cover
335 less HSD during match-play they were shown to cover more RHSD then that previously
336 reported for domestic players (1). However, Macutkiewicz and Sunderland (16) reported the
337 average HSD (m ; $>15.1 \text{ km}\cdot\text{h}^{-1}$) covered by players was $852 \pm 268 \text{ m}$ ($17.8 \pm 67 \text{ m}\cdot\text{min}^{-1}$).
338 However, differences in selected speed thresholds across research make it hard to compare
339 results. The differences in RTD and RHSD outputs may be reflective of the influence that the
340 rolling substitution rule has on the game. The observed data may inform coaches of potential
341 strategies to maximize this rule by employing a specific rolling substitute policy based on GPS
342 and HR data of players. Indeed, coaches may decide to make substitutions based on reductions
343 in HSD and RHSD given that these variables have been previously linked to technical outputs
344 during match-play (8).

345

346 ** INSERT FIGURE 2 NEAR HERE **

347

348

349 Monitoring HR responses during match-play provides an indication of the internal
350 physiological load during game play actions (32). The HR_{peak} of the players was $199 \pm 1 \text{ b}\cdot\text{min}^{-1}$
351 ¹ with the HR during match-play of $171 \pm 1 \text{ b}\cdot\text{min}^{-1}$ reflective of an average exercise intensity
352 regardless of position of $86 \pm 8 \%$ HR_{peak} . During competitive match-play players had a HR_{peak}
353 of $96 \pm 3.5 \%$. Sell and Ledesma (29) examined HR responses in NCAA division I colligate
354 female hockey players and reported HR_{peak} responses of $94.6 \pm 3.3 \%$. Regardless of position
355 Sell and Ledesma (29) reported the HR_{peak} of international female hockey players was 203 ± 7
356 $\text{b}\cdot\text{min}^{-1}$ which is higher than previously observed by MacLeod et al. (15) ($190 \pm 9 \text{ b}\cdot\text{min}^{-1}$) and
357 our current observations. The time spent $> 85 \%$ HR_{peak} has been previously shown to be
358 associated with improvements in aerobic capacity while also being linked to an improved
359 physical activity profile during match play (9,23). Therefore, it is important for coaches to
360 monitor the time spent $> 85\%$ HR_{peak} to best ensure players attain these intensities during
361 training, this will ultimately best equip them to compete during match-play. The players in the
362 current investigation spent on average 31 min $> 85\%$ HR_{peak} suggesting that a high percentage
363 of match-play is played at high-intensity.

364

365 ** INSERT FIGURE 3 NEAR HERE **

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

377

378 It has been suggested that players will regulate distance travelled at low-speed to ensure
379 they have the ability to produce high-speed efforts when required during match-play (2). Our
380 data showed there to be no significant difference in physical demands across the halves of play
381 in elite female hockey. Interestingly, the observed decrements in physical activity were position
382 specific with the defenders showing the highest level of reduction across the halves when
383 compared to other positions. Defenders were shown to have on average a 5% decrease in RTD
384 and significant reduction of 10 % in RHSD across halves of play. Midfielders increased the
385 RTD and RHSD covered by 2 % across halves, while forwards were shown to increase the
386 RTD covered by 1% with no change in RHSD. The findings of the current study differ to those
387 by Vescovi and Frayne (33) suggesting that in collegiate female hockey both the defenders and
388 midfield players would cover less RTD and RHSD across halves of play. Although the results
389 of the current study show there to be a non-significant difference, in a sport setting a 5%
390 decrement in performance could be deemed a practical significant decrease in HSD covered.
391 Previous studies have shown that the most successful teams cover a greater HSD and sprint
392 distance (8,27). The findings of the current study show that positional roles influence physical
393 activity during female hockey match-play. However, it is unclear whether the reduction is
394 based on fatigue, tactical factors or physiological factors (2,21,32). Keeping this in mind,
395 having a clear and concise substitution policy within the squad could reduce fatigue due to
396 increased recovery between bouts of play and in-turn reduce the effect of positional demands
397 on the physical activity profiles of players.

398

399

****INSERT FIGURE 4 NEAR HERE****

400 Previous studies have attempted to analyze the positional profile of female field hockey
401 across various competitive standards (7,16,29,33). Similar to previous studies in female soccer
402 (18,20), rugby union (31,35) and rugby 7's (34) a position specific profile was observed for
403 female hockey players. Specifically, defenders spend significantly more time in match-play
404 and covered more TD than other positions. However, when the relative outputs were
405 considered the midfield and forwards had significantly higher relative intensities for physical
406 activity. Notably, midfielder's due to their nomadic nature covered more HSD, this may be
407 related to the fact that these players provide a tactical link between defence and attack when in
408 and out of possession. This specific tactical difference allows them to achieve greater distances
409 as they must travel the length and breadth of the field during match-play. The observed
410 decrements in physical activity were also position specific, with defenders shown to have the
411 highest decrements in running performance covering $6 \text{ m} \cdot \text{min}^{-1}$ less during the second half
412 when compared to the first half. However, it is not possible to determine whether the decrement
413 is related to fatigue or pacing strategies adapted by defenders during match-play (2). Regardless
414 of the above, the results have practical implications for coaches on when best to make player
415 interchanges during match-play.

416

417 The current study agrees with the previous findings of Sell and Ledesma (29) and
418 Macutkiewicz and Sunderland (16) that reported no differences in HR_{mean} and HR_{peak} across
419 positional lines of play within elite female hockey cohorts. However, positional differences
420 were observed regarding time spent at different levels of intensity, Sell and Ledesma (29)
421 suggested that the forwards spent more time at higher percentages of HR_{peak} . In contrast to the
422 above findings our observations show that defenders spend more time $>85\% \text{ HR}_{\text{peak}}$. Our
423 results are in agreement with Macutkiewicz and Sunderland (16) who suggested that although
424 the forwards performed more moderate - high intensity exercise they were rewarded with more
425 time to recover due to the roll on roll off substitution rule resulting in defenders having more
426 time spent at higher percentages of HR_{peak} . The results of this study need to be considered
427 within the context of the study's limitations. Firstly, with no technical data it is very difficult
428 to assess the efficiency of players' physical activity. Additionally, although acceptable validity
429 and accuracy was reported for the specific GPS units used within the current study, it should
430 be noted that previous research has questioned the accuracy of GPS for the measurement of
431 high-speed movement (10). Finally, each player is biologically different in both stature and
432 physical capacity. With this in mind the authors advocate the development of individualised
433 player specific running thresholds for female hockey players (4). The results of this study need

434 to be interpreted within the context of the studies limitations. No measure of match dynamics
435 (win or loss) and tactical styles of play were considered. Recently, studies have shown there to
436 be match to match variation in other field sports (5,25). Future studies should report the typical
437 match-to-match variation of GPS variables with elite female field hockey. To date no studies
438 have examined the physical activity profiles of elite female field hockey players during a
439 condensed high intensity period with quick turnarounds such as an international tournament
440 environment. Therefore, we recommend that the changes in physical activity be reported for
441 these highly demanding periods. Finally, we suggest that future research should consider the
442 current advancements in field sports and the known energetic cost of accelerated movements.
443 Therefore, an analysis of the metabolic power profile of elite international female hockey is
444 warranted to improve coaches understanding of the energetic cost associated with competitive
445 match-play.

446

447 **PRACTICAL APPLICATIONS**

448

449 The current study provides an insight into the physical and physiological demands of
450 elite international female hockey across both positions and halves of play. During competitive
451 match-play players are likely to cover 61 % of their TD $> 8 \text{ km} \cdot \text{h}^{-1}$ irrespective of position. Our
452 results showed that defenders spent more time in match-play and covered more TD when
453 compared to other positions. Midfielders were found to cover on average 68 % of their TD
454 distance $> 8 \text{ km} \cdot \text{h}^{-1}$ which was more than defenders (9 %) and the forwards (2%). When high-
455 speed was considered, midfielders covered over 15% of their TD $> 16 \text{ km} \cdot \text{h}^{-1}$ which was similar
456 to forwards (14 %) but significantly greater than defenders (10%). The results highlight the
457 need for coaches to consider the positional profile of match-play prior to planning training
458 regimen in order to best replicate players' specific match-play physical activity profile. For
459 example, midfield players should be placed into drills that allow them to cover more HSD
460 while forwards should be placed into more intense drills that allow them to cover more distance
461 in a shortened period in order to increase their RTD to that similar of match-play. Previous
462 research has shown a strong linear association between HR and volume of oxygen
463 consumption, which can then be used to determine the level of intensity and the physiological
464 demands in competitive match-play (6). Therefore, with the use of HR monitors the monitoring
465 time spent at different zones and average HR can be used to effectively reflect the aerobic
466 metabolic demands of competitive match-play (6). Our data therefore confirm that competitive
467 match-play is mainly aerobic in nature. At set time points within a periodised plan coaches

468 should aim to have specific periods of training drills $>85\% \text{HR}_{\text{peak}}$. We observed that defenders
469 were the only position to have a notable decrement in running performance across halves of
470 play. However, in order to reduce the likelihood of these reductions in physical activity it may
471 be suggested that half-time nutritional strategies, in addition to a half-time re-warm up strategy
472 be implemented by coaches. Overall the current study provides normative data on the physical
473 activity and physiological profiles of elite international female hockey players. From these
474 findings, it may be suggested that coaches use these data to implement position specific training
475 drills in order to best replicate the demands of each position. Furthermore the data will aid
476 coaches in developing specific player interchange protocols during match environments.

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628 **TABLE AND FIGURE CAPTIONS**

629

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

633

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

636

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

640

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

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

644

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

647

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

651

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

654

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

658

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

661

662 A significant difference in time spent $> 85\% \text{HR}_{\text{peak}}$ (*) between the first and second halves (p
663 = 0.04, $\eta = 0.09$, Small). The letters a,b,c signifies the positional variation between the
664 defenders (a), midfield (b) and forwards (c) ($p \leq 0.001$ $\eta = 0.22$, Medium). The defenders were
665 observed to spend significantly more time $> 85\% \text{HR}_{\text{peak}}$ across all three positions. The number
666 1,2,3,4 signifies the variation in time spent in specific heart rate zones. The defenders were
667 observed to spend significantly more time in zones 1 and 2. The midfield and forwards were
668 observed to spend significantly more time in zones 2, 3 and 4 ($p \leq 0.001$ $\eta = 0.19$, Medium).

669

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

672

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

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696 **Table and Figures**697 **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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700 **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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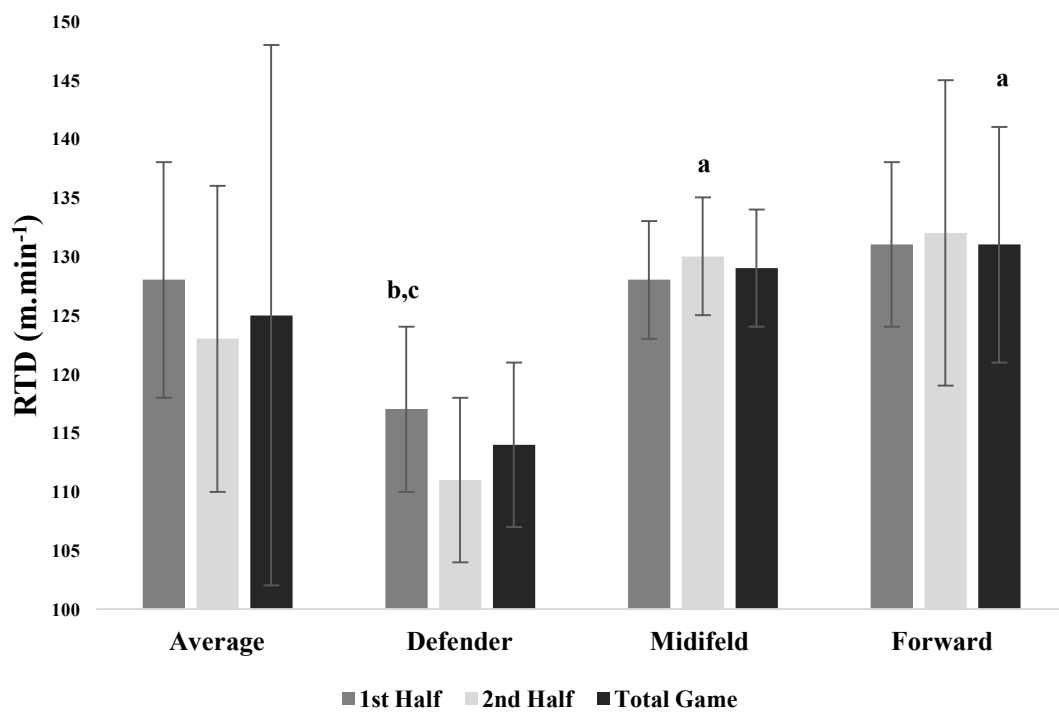
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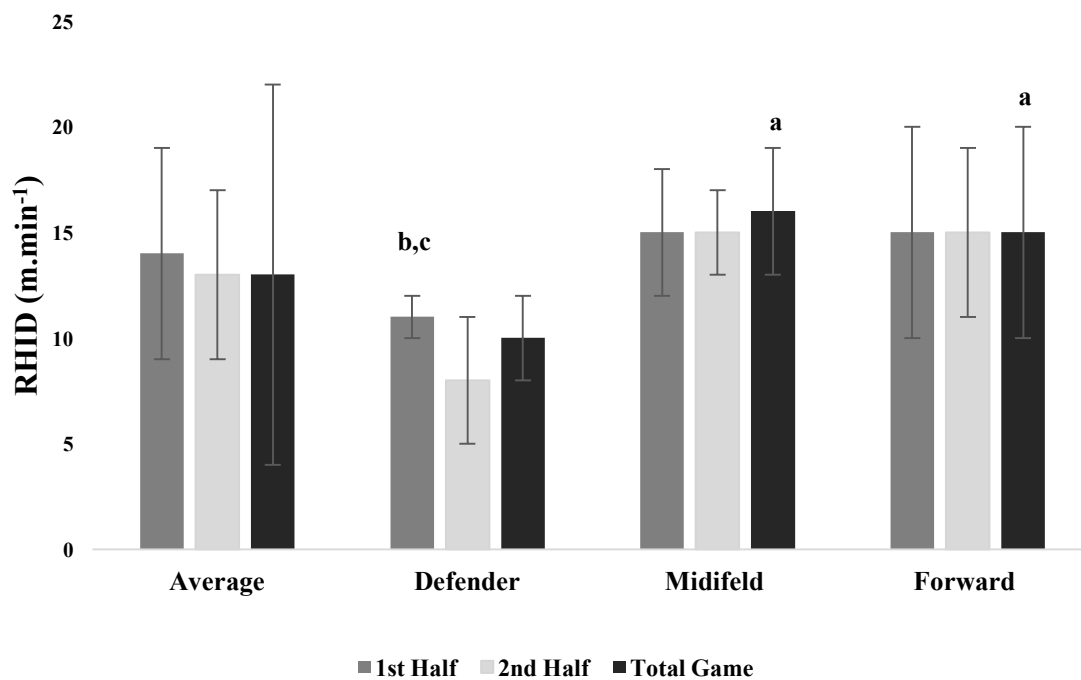
712 **Figure 1.**



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715 **Figure 2.**

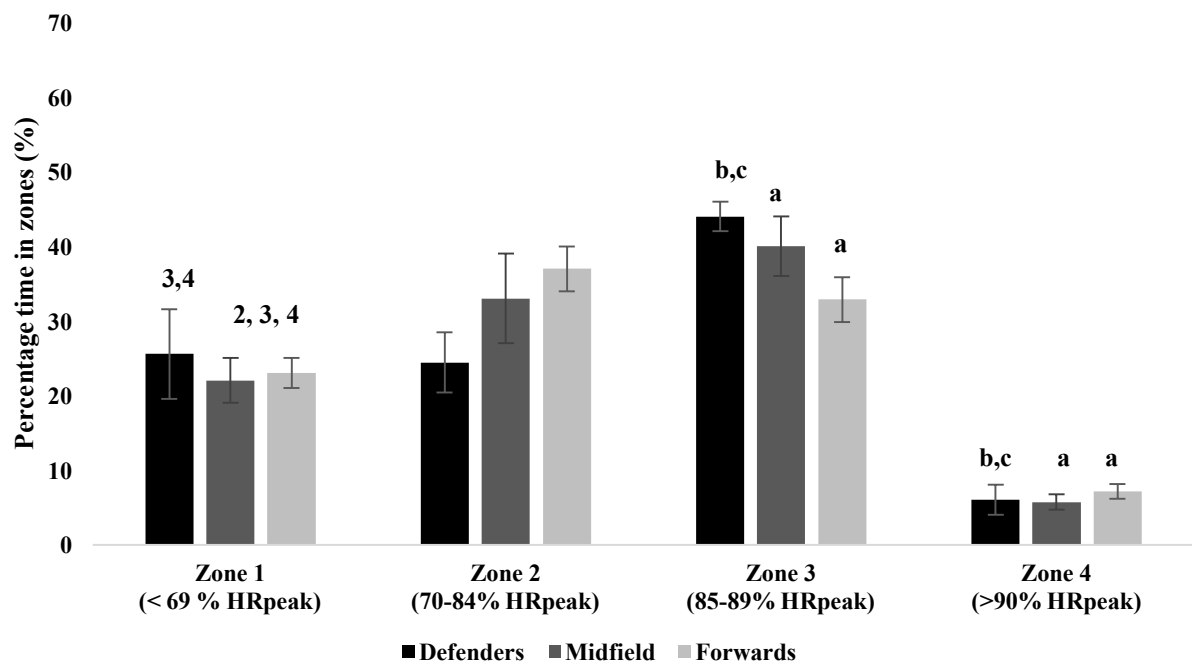


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719 **Figure 3.**

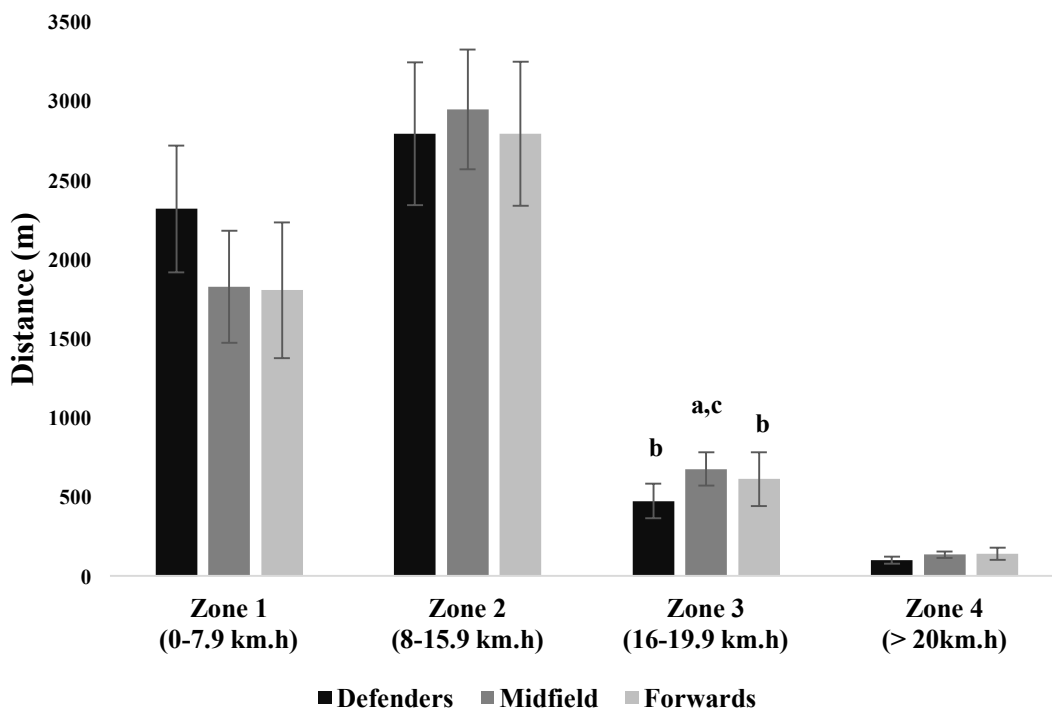


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722 **Figure 4.**

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