1
2 **The influence of match phase and field position on collective team behaviour in Australian**
3 **Rules Football**
4
5

6 **Authors**
7 Jeremy. P. Alexander [1]*., Bartholomew Spencer[1]., Alice J. Sweeting [1, 3]., Jocelyn. K. Mara [2]., Sam Robertson [1, 3]
8
9 **Department/Institution**
10 [1]Institute for Health and Sport (IHES)
11 Victoria University,
12 Melbourne VIC, Australia
13
14 [2]Research Institute for Sport and Exercise
15 University of Canberra
16 Bruce, ACT, 2617, Australia
17 (02) 6201 5111
18
19 [3]Western Bulldogs Football Club
20 Melbourne, VIC, Australia
21
22 ***Corresponding author**
23 **Email: jeremyalexander60@gmail.com**
24

25 **Word Count: 3770**

26 **Number of Figures: 5**

27

28

29 **ABSTRACT**

30

31 This study investigated the influence of match phase and field position on collective team

32 behaviour in Australian Rules football (AF). Data from professional male athletes (years 24.4 $\pm$

33 3.7; cm 185.9 $\pm$ 7.1; kg 85.4 $\pm$ 7.1), were collected via 10 Hz global positioning system (GPS)

34 during a competitive AFL match. Five spatiotemporal metrics (x-axis centroid, y–axis centroid,

35 length, width, and surface area), occupancy maps, and Shannon Entropy (ShannEn) were analysed

36 by match phase (offensive, defensive, and contested) and field position (defensive 50, defensive

37 midfield, forward midfield, and forward 50). A multivariate analysis of variance (MANOVA)

38 revealed that field position had a greater influence on the x-axis centroid comparative to match

39 phase. Conversely, match phase had a greater influence on length, width, and surface area

40 comparative to field position. Occupancy maps revealed that players repositioned behind centre

41 when the ball was in their defensive half and moved forward of centre when the ball was in their

42 forward half. Shannon Entropy revealed that player movement was more variable during offence

43 and defence (ShannEn $= 0.82 - 0.93$) compared to contest (ShannEn $= 0.68 - 0.79$). Spatiotemporal

44 metrics, occupancy maps, and Shannon Entropy may assist in understanding the game style of AF

45 teams.

46

47 **Key Words: Performance analysis, Team tactics, Game style**
48

INTRODUCTION

49

50

51 Collective team behaviour in invasion sports refers to how individual players position themselves

52 across a field of play to form an overall group organisation (Rein and Memmert 2016). This

53 behaviour has been used to describe team tactics or game style, whereby repetitive patterns of

54 movement are formed (Sampaio and Macas 2012). Collective team behaviour has become a central

55 component of match analysis (Clemente, Sequeiros et al. 2018) due to its established relationship

56 with performance outcomes (Clemente, Couceiro et al. 2013, Goncalves, Marcelino et al. 2016,

57 Rein and Memmert 2016) and the capability to provide greater context to match events (Lamas,

58 Barrera et al. 2014).

59 Collective team behaviour has typically been defined via spatiotemporal metrics including

60 x-axis centroid, y-axis centroid, length, width, and surface area (Frencken, Lemmink et al. 2011,

61 Clemente, Couceiro et al. 2013, Folgado, Lemmink et al. 2014). The team centroid represents the

62 geometric centre of all players on the field, which can be assessed in both the x-axis and y-axis,

63 team length and width describes the distance between the two players furthest apart along the pitch

64 and across the pitch respectively, and the team surface area signifies the region that encompasses

65 all players across a field of play (Bartlett, Button et al. 2012). More recently, studies have

66 visualised occupancy maps or heat maps and combined them with a measure of entropy to

67 determine the variability of player movement (Couceiro, Clemente et al. 2014, Silva, Aguiar et al.

68 2014, Clemente, Sequeiros et al. 2018). To provide additional context to the understanding of

69 collective behaviour, investigations have been separated into various phases of match play, such

70 as offence and defence (Castellano, Álvarez et al. 2013, Clemente, Couceiro et al. 2013,

71 Bialkowski, Lucey et al. 2014).

3

72   Research in football has considered the *x*-axis centroid and occupancy maps to suggest

73   teams may be more attacking by positioning players higher up the field in both offence and defence

74   during home matches compared to away matches (Lucey, Oliver et al. 2013, Bialkowski, Lucey et

75   al. 2014). This behaviour may be associated with an increased possession in the forward third and

76   a greater number of shots on goal (Lucey, Oliver et al. 2013, Bialkowski, Lucey et al. 2014).

77   Irrespective of match location, a conservative approach is generally taken, with the team *x*-axis

78   centroid located in their defensive half (Clemente, Couceiro et al. 2013). Investigations in football

79   have used the length, width, and surface area to propose that whilst defending, teams will aim to

80   compress the field of play by decreasing the area in which attacking players can operate (Vilar,

81   Araújo et al. 2013). Increasing the number of defensive players surrounding an attacking team

82   taking a shot at goal is associated with a concomitant decrease in successful scoring attempts

83   (Ensum, Pollard et al. 2004, Wright, Atkins et al. 2011). Conversely, when teams are in offence

84   they will attempt to spread the opposing defence to create more space (Castellano and

85   Casamichana 2015). Defending players are then compelled to either restrict the impact of these

86   players or hold their position to protect space closer towards their goal (Vilar, Araújo et al. 2013).

87   Higher-ranking teams in football may therefore be more effective at accomplishing this as they

88   commonly produce greater values of length, width, and playing space compared to their lower-

89   ranked counterparts (Castellano, Álvarez et al. 2013).

90   Due to the continuous nature of invasion sports, it is difficult to associate discrete parts of

91   collective team behaviour with a certain type of play (Lucey, Oliver et al. 2013). Specifically, it

92   may be somewhat simplistic to assign specific movement behaviour to a particular tactic or game

93   style, as a team's movement behaviour is constantly influenced by emerging aspects of match play

94   (Rein and Memmert 2016). Therefore, collective team behaviour may not necessarily be a

4

95 preconceived team tactic or game style but rather an adaption to the general state of play (Rein and

96 Memmert 2016). Thus, to gain a more comprehensive representation of team tactics or game style,

97 researchers should account for contextual variables, such as match phase and field position

98 (Castellano, Álvarez et al. 2013, Clemente, Couceiro et al. 2013, Alexander, Spencer et al. 2018).

99 Research into collective team behaviour in Australian Football (AF) also remains largely absent,

100 with only one study reported to date (Alexander, Spencer et al. 2018).

101   Australian Football is an invasion sport where teams compete on an oval shaped field

102 (length = ~160 m, width = ~130 m). The match is separated into four quarters, contested by 22

103 players per team, with 18 on the field and 4 on an interchange bench (Gray and Jenkins 2010).

104 Initial research in AF identified that teams display large variations in overall positioning

105 throughout a match that may be influenced by the position of the ball (Alexander, Spencer et al.

106 2018). Therefore, field position of the ball may influence collective team behaviour (Alexander,

107 Spencer et al. 2018). However, the extent to which collective team behaviour is influenced by

108 match phase in relation to field position is yet to be investigated.

109   Determining collective team behaviour whilst accounting for contextual variables may

110 provide a greater understanding of team tactics or game style. Therefore, this study investigated

111 the influence of match phase and field position on collective team behaviour in AF.

112

113   **METHODS**

114

115 Data were collected from 22 male professional AF players (years 24.4 ± 3.7; cm 185.9 ± 7.1; kg

116 85.4 ± 7.1), recruited from a single team in the Australian Football League (AFL) competition.

117 Participants took part in a match as part of the regular premiership season. All participants received

118 information about the requirements of the study via verbal and written communication, and

119 provided their written consent to participate. The University Ethics Committee approved the study.

120   The match took place on an oval shaped ground using dimensions 159.5 m x 128.8 m

121 (length x width) with four 20-min quarters. Spatiotemporal data for all participants were collected

122 using 10 Hz GPS devices (Catapult Optimeye S5, Catapult Innovations, Melbourne, Australia).

123 The devices were housed in a sewn pocket in the jersey that is located on the upper back. The

124 number of GPS satellites were greater than 8 packets per second, which ensured adequate signal

125 quality (Corbett, Sweeting et al. 2017).

126   Spatiotemporal data was exported in raw 10 Hz format. Each file contained a global time

127 stamp and calibrated location (x- and y- location). Match phase was determined via which team

128 had possession of the ball (offensive, defensive or contest). The offensive phase was recorded

129 when a team first gained possession of the ball and maintained it for at least a second and ended

130 when the opposing team gained possession of the ball for at least a second or there was a stoppage

131 in play. For example, the team scored or the ball went out of bounds (Yue, Broich et al. 2008).

132 Using the same conditions, the defensive phase was recorded when the opposing team had

133 possession of the ball (Yue, Broich et al. 2008). If neither team had possession of the ball, for

134 example, when the officiating umpire returned the ball to play, the phase was considered to be in

135 contest until a team gained possession of the ball for at least one second. All periods where the

136 ball was out of play, for example, when there was a break between periods of play, celebration

137 after goals, were excluded from the investigation. Field position of the ball was separated into four

138 zones (defensive 50; D50, defensive mid; DMID, forward mid; FMID, forward 50; F50) by the

139 two 50 m arcs and the centre of the ground (see Figure 1). The centre of the ground was signified

140 as 0, 0. Match phase and field position were analysed via video observation and recorded to the

6

141 nearest second by a commercial statistical provider (Champion Data Pty Ltd, Melbourne,

142 Australia). Previous investigations have assessed the validity and reliability of similar match

143 events (Robertson, Gupta et al. 2016). Positional data was then synchronised with match phase

144 and field position data using the respective global timestamps. This was established using the

145 initial point when the two widest players on the field converged from a stationary position prior to

146 start of each quarter.

147
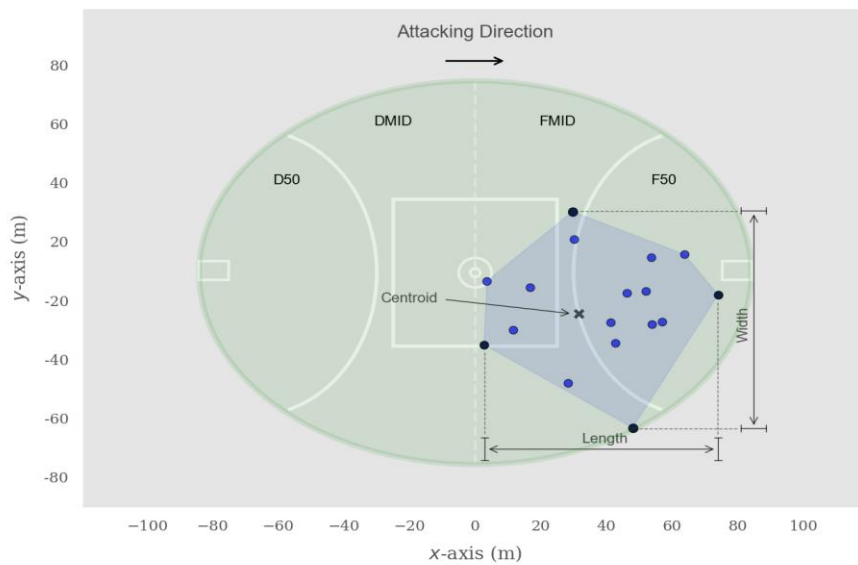
148
149 **Figure 1:** Four field position zones and spatiotemporal metrics including centroid, length, width,
150 and surface area.
151

152   Five spatiotemporal metrics (Figure 1) were derived from the data to describe collective

153 team behaviour. Team centroid was calculated as the mean (x, y) position of all players on the field

154 (Frencken, Lemmink et al. 2011). Two measures were derived from the centroid position. These

155 were the distance in the *x*-axis centroid (m) and the distance in the *y*-axis centroid (m) (Frencken,

156 Lemmink et al. 2011). The team surface area was calculated as the total space (m) covered by a

157 single team (Frencken, Lemmink et al. 2011). Team length was measured as the distance between

158 the most forward and most backward player in the *x*-axis (m) and team width was defined as the

159 distance between the two most lateral players on the ground in the *y*-axis (m) (Frencken, Lemmink

160 et al. 2011). Variability of player movement was visualised via occupancy maps (Couceiro,

161 Clemente et al. 2014, Silva, Aguiar et al. 2014), which represent the density of players across a

162 given area (Silva, Aguiar et al. 2014). The occupancy maps were combined with Shannon Entropy

163 (ShannEn) to provide an enhanced understanding of team movement variability. To calculate

164 ShannEn, the field of play was quantised into bins of equal size ($1m^2$) to provide adequate spatial

165 resolution (Couceiro, Clemente et al. 2014). The total count from each bin was used to determine

166 the total time spent in each bin. A probability distribution of the total time spent in each bin was

167 then used to determine the variability of a player being located in a specific bin. Both the heat

168 maps and ShannEn values were normalised to total time spent in each position on the field for each

169 match phase. Synchronisation and analysis were undertaken using the computational package

170 Python version 3.2 with *Spyder*, which is part of the Anaconda software suite (www.python.org).

171

172 **Statistical Analyses**

173 Comparison of team *x*-axis centroid, *y*-axis centroid, length, width, and surface area were assessed

174 between match phase (3 levels: Offence, Defence, Contest) and field position (4 levels: D50,

175 DMID, FMID, F50), via a multivariate analysis of variance (MANOVA). Homogeneity was

176 analysed using the Levene Test, which resulted in a lack of uniformity between match phase and

177 field position. The *F* test was used to combat homogeneity violations due to the fact the total

178   number of samples is in each group was essentially equal (Vincent 1999). Due to the non-

179   homogeneity of the time series data, the Central Limit Theorem was considered, which allowed

180   the assumption of normality to be made (Akritas 2004). Effect sizes were determined by

181   calculating partial eta-squared (η_p^2) and was considered as small ($\eta_p^2 < .06$), moderate ($\eta_p^2 > .06$ η_p^2

182     $< .15$) or large ($\eta_p^2 \geq .15$) (Cohen 1988). Significant p values reported are $< .001$ unless otherwise

183   stated. These calculations were determined using SPSS, v21.0; Inc., Armonk, NY, USA). Using

184   Shannon Entropy *S*, the probability $p_{(i)}$ of finding a player in bin *i* was measured via quantising

185   the field into *n* bins. Entropy was then normalised *N* to total match time spent in each position on

186   the field for each phase of play to return a relative number between 0 and 1.

187

188 $$S\ (\%) = -\sum_{i=0}^{n-1} p\ (i) \log p\ (i) \log N$$

189

190   A low ShannEn (near 0) suggests the variability of player movement is low (Couceiro, Clemente

191   et al. 2014). A high ShannEn (near 1) indicates the variability of player movement is high

192   (Couceiro, Clemente et al. 2014). These calculations were completed using the computational

193   package Python version 3.2 with *Spyder*, which is part of the Anaconda software suite

194   (www.python.org).

195

196   **RESULTS**

197

198   Total differences between match phase and field position for each spatiotemporal metric are

199   displayed in Figure 2. Individual playing sequences exhibited over time for field position and

9

200 match phase are represented in Figure 3, while the distribution of these sequences are displayed in

201 Figure 4. Heat maps and ShannEn values displaying player movement variability between match

202 phase and field position are presented in Figure 5. The team observed in this study won the game

203 109 – 38.

204   Overall, field position had a greater influence on the *x*-axis centroid ($\eta_p^2 = .41$) when

205 compared to match phase. Although, match phase had a greater influence on length ($\eta_p^2 = .06$),

206 width ($\eta_p^2 = .27$), and surface area ($\eta_p^2 = .14$) when compared to field position. The *x*-axis centroid

207 in the D50 was further behind centre when compared to the DMID (-10.7; 95% CI -11.2 – -10.2),

208 FMID (-35.3; 95% CI -35.7 – -34.9) and the F50 (-48.1; 95% CI -48.6 – -47.7). The *x*-axis centroid

209 in the DMID was also recorded further behind the FMID (-24.6; 95% CI -25.0 – -24.1) and F50 (-

210 37.4; 95% CI -37.9 – -37.0), while the *x*-axis centroid in the FMID was recorded forward of centre

211 it was still behind the F50 (-12.9; 95% CI -13.3 – -12.5). Length was greater during the DMID

212 when compared to the D50 (22.9; 95% CI 22.3 – 23.6) and F50 (22.9; 95% CI 22.3 – 23.6). Length

213 in the FMID was also greater than the D50 (8.1; 95% CI 7.6 – 8.7). Width was reduced in the D50

214 when compared to the DMID (-16.7; 95% CI -17.2 – -16.2), FMID (-10.6; 95% CI -11.0 – -10.2),

215 and F50 (-14.5; 95% CI -14.9 – -14.0). The surface area in the DMID was larger when compared

216 to the D50 (1900.3; 95% CI 1857.9 – 1942.8), FMID (976.4; 95% CI 934.4 – 1018.3), and F50

217 (1054.0; 95% CI 1012.3 – 1095.7). Surface area in the FMID was also larger when compared to

218 the D50 (923.9; 95% CI 885.1 – 962.8) and F50 (77.6; 95% CI 39.6 – 115.7).

219

10
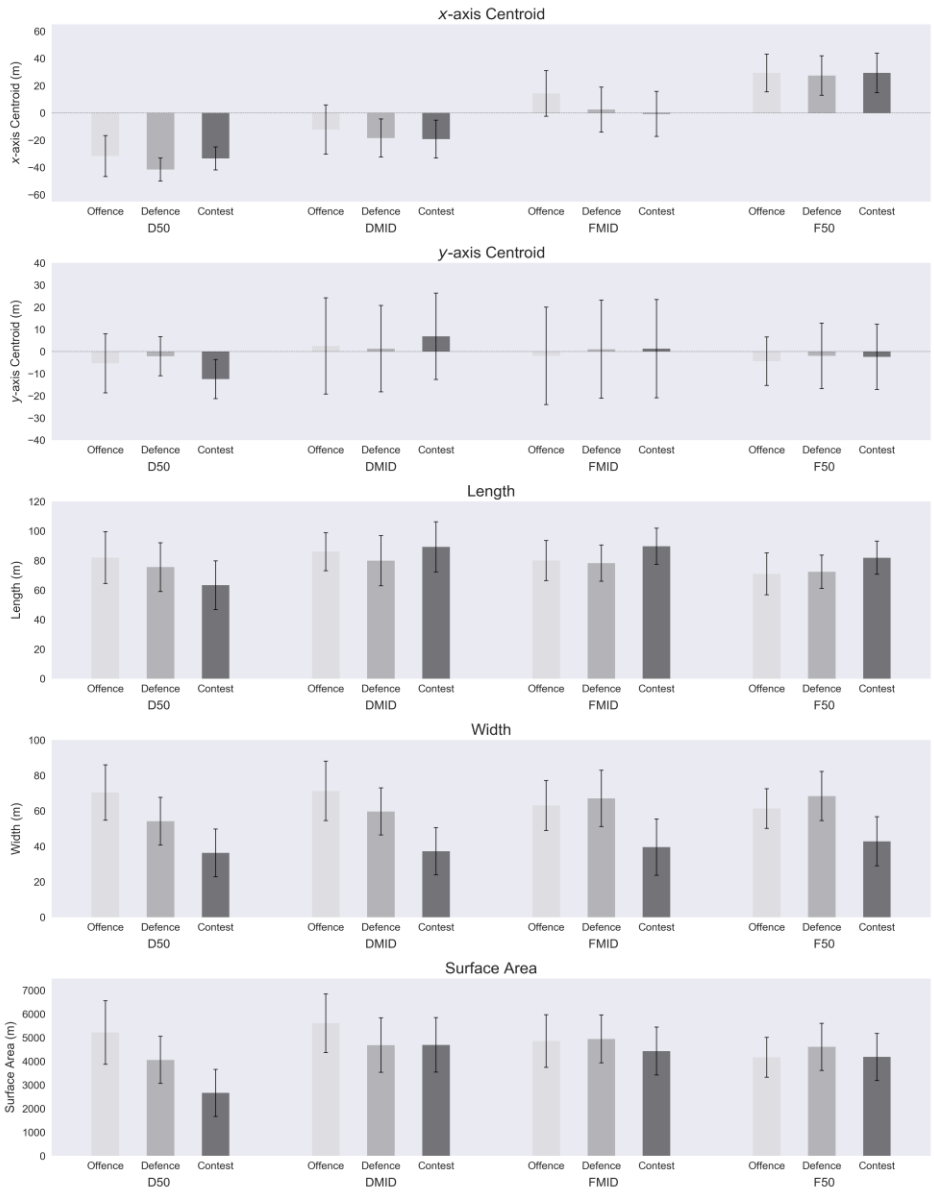
Figure 2: Comparison of mean ± standard deviation between match phase and field position of spatiotemporal metrics

223 Between-phase analysis recorded the *x*-axis centroid higher up the ground during offence when

224 compared to defence (3.6; 95% CI 3.1 – 4.0) and contest (3.3; 95% CI 2.6 – 4.0). Length was

225 greater during offence compared to defence (4.7; 95% CI 4.2 – 5.3), while contest was greater than

226 offence (3.5; 95% CI 2.5 – 4.5) and defence (8.2; 95% CI 7.2 – 9.3). Width was greater during

227 offence when compared to defence (3.3; 95% CI 2.9 – 3.8) and contest (27.9; 95% CI 27.2 – 28.7).

228 Width was also greater during defence compared to contest (24.6; 95% CI 23.8 – 25.4). Surface

229 area was greater during offence compared defence (397.5; 95% CI 359.8 – 435.2) and contest

230 (794.2; 95% CI 727.4 – 861.0). Surface area during defence was also greater than contest (396.8;

231 95% CI 327.8 – 465.8).

232   Visual inspection of the distribution plots (Figure 4) displayed similar time duration for

233 offensive and defensive sequences with the majority of playing sequences between 0 – 20 seconds.

234 Total time during contest was reduced with the majority of sequences measuring between 0 – 10

235 seconds.
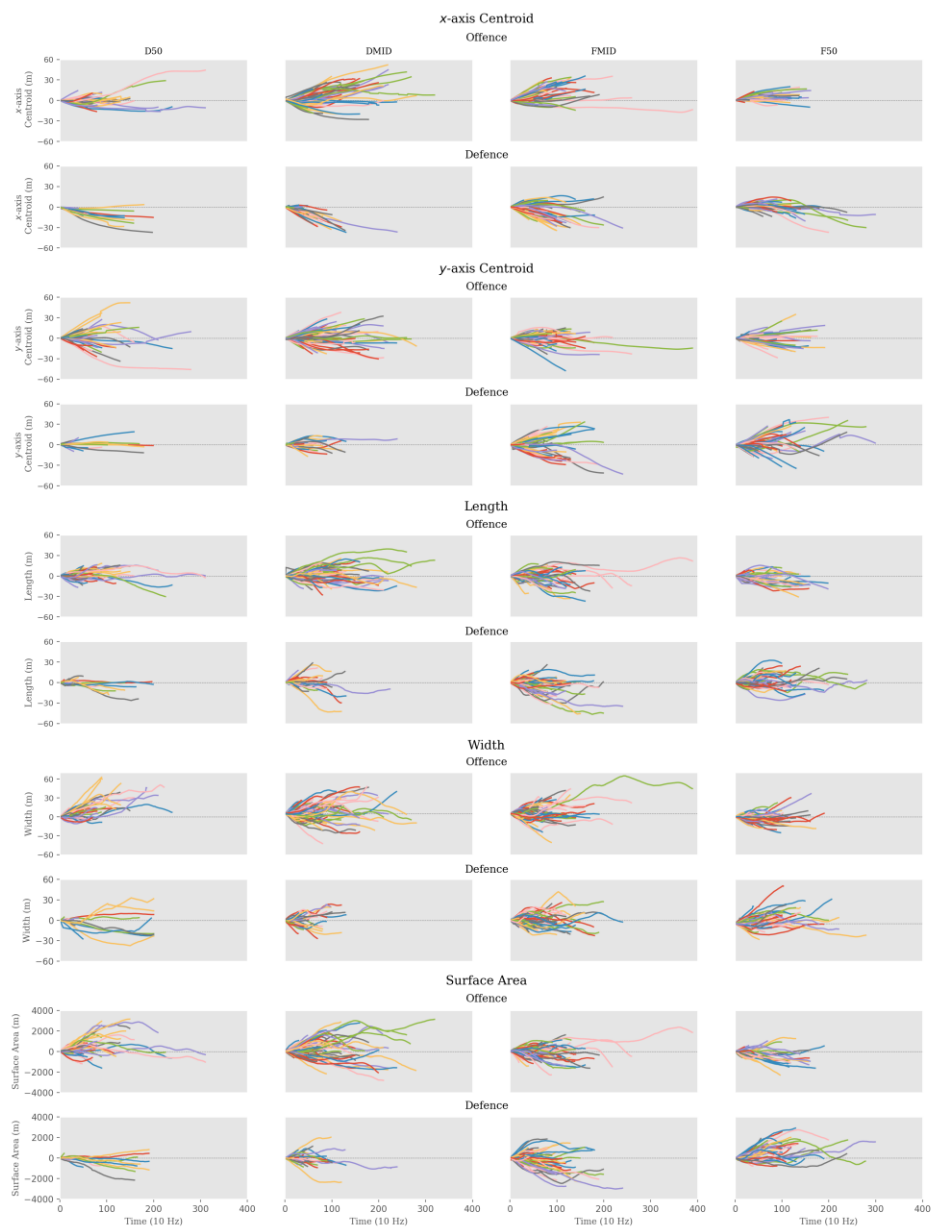
Figure 3: Comparison of individual instances of spatiotemporal metrics in relation to the duration of time for match phase and field position
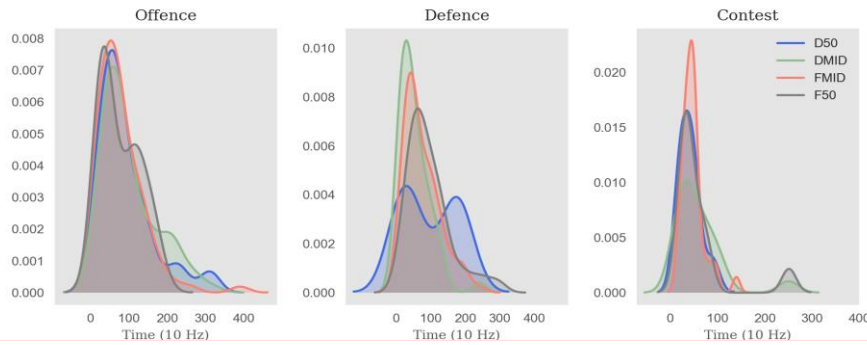
239

240 **Figure 4:** Between match phase comparison of the distribution of total time for field position

241

242   ShannEn values (Figure 5) were greater during offence and defence compared to contest.
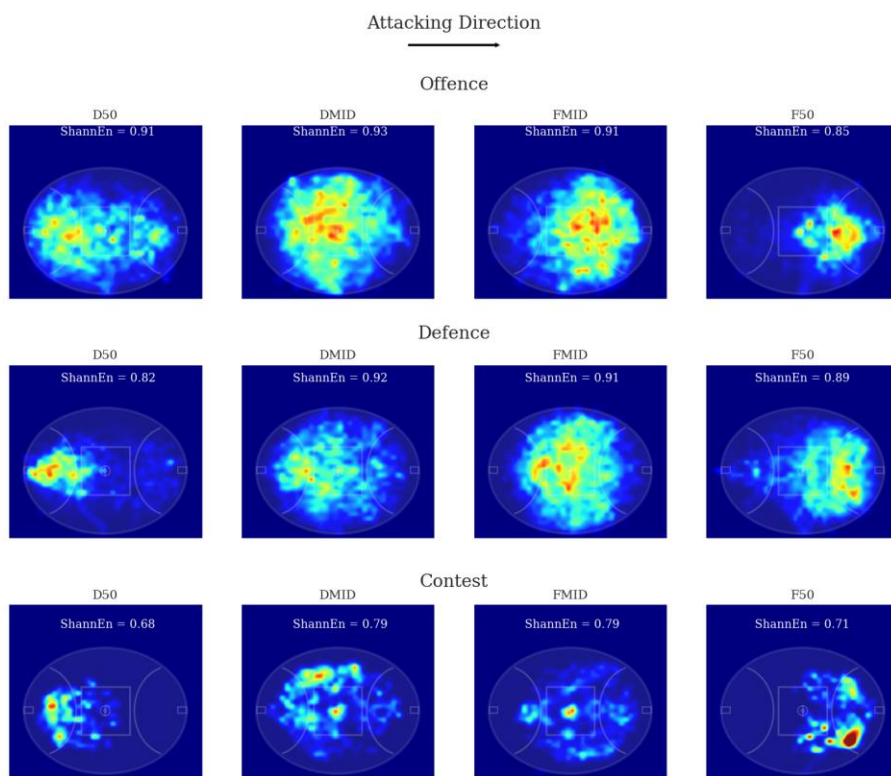
243 Between field position analysis indicated that variability of team movement decreased during

244 defence when in the D50 and in offence when in the F50. ShannEn values were greater during

245 contest when the ball was in the middle of the ground compared to D50 and F50.

14

Figure 5: Comparison of occupancy maps and ShannEn values for match phase and field position

DISCUSSION

This is the first study to investigate the influence of match phase and field position on collective team behaviour in AF. This proof of concept study may be used to provide a complementary framework to add to existing match analyses common in AF. Specifically, the addition of spatiotemporally-derived metrics relating to collective team behaviour has the potential to provide

255 both enhanced insights and context to existing consideration of discrete team and player

256 performance indicators.

257   A predominant finding was field position had a greater influence on the *x*-axis centroid

258 when compared to phase of play. Conversely, phase of play had a greater influence on length,

259 width, and surface area when compared with field position. Players collectively transitioned closer

260 to their goal when the ball was in their defensive half and pressed higher up the field when the ball

261 was in their forward half. Variation in player movement, as signified by ShannEn, increased

262 through FMID and DMID compared to F50 and D50 and during offence and defence when

263 compared to contest.

264   Overall, the majority of players were positioned close to where the ball was situated. The

265 density of players was more pronounced when the ball was in the D50 or F50 and further amplified

266 when in the contested phase. Length, width, and surface area were also reduced under these

267 circumstances. This type of behaviour may be associated with players trying to reduce the amount

268 of space an opposition can operate in (Vilar, Araújo et al. 2013) and is also representative of AFL

269 rules, whereby no movement restrictions are imparted on players. This behaviour could be

270 beneficial when defending in the D50 as it may be more difficult for the opposing team to achieve

271 an effective shot on goal if an increased number of players are located within this area (Ensum,

272 Pollard et al. 2004, Wright, Atkins et al. 2011). Alternatively, when the ball is located in the F50

273 it may be more difficult for the opposing team to successfully move the ball out of this area if

274 players have setup an effective 'barrier' behind the ball. Increased width and variation in player

275 movement throughout the middle of the ground comparative to the F50 and D50 areas may also

276 be somewhat attributed to the oval shaped field dimensions of an AF ground. However, reduced

277 entropy in these areas during the contested phase suggests movement variability may differ

16

278   between field position and match phase. Increased variability during offence in the D50, DMID,

279   and FMID could indicate players may be utilising various movement patterns to disrupt opposing

280   defensive structures (Garganta 2009). Reduced movement variation during the contested phase

281   may reflect the inactive period, prior to a change in match phase. The duration of playing sequences

282   during the contested phase was also reduced when compared to offensive and defensive phases. In

283   the present study, while players may produce less movement variation during contest, they are

284   required to be prepared to react when either team gains possession of the ball.

285   Studies investigating the physical movement output of team sport athletes through the

286   duration of time are ubiquitous (Brewer, Dawson et al. 2010, Wisbey, Montgomery et al. 2010,

287   Dwyer and Gabbett 2012). However, there is limited research on the duration of time with respect

288   to collective team behaviour. Findings from the present study indicate the time duration of playing

289   sequences before a change in field position are generally between 0 and 20 seconds for offensive

290   and defensive phases and 0 to 10 seconds for the contested phase. The combination of

291   spatiotemporal metrics, heat maps, and entropy measures may assist in measuring particular

292   collective team behaviour, which can be used to design more representative training regimes. For

293   instance, if the ball is in the forward half, players may be instructed to press higher up the field in

294   a certain period of time to generate enough pressure to keep the opposition from moving outside

295   this zone. Alternatively, an aim to maintain possession of the ball may be more attainable if surface

296   area is being created when initially gaining possession of the ball. Opposition analysis may also

297   be benefit from a greater understanding of rival collective team behaviour. For example, an

298   opposing team that quickly transitions players deep in their defensive end after losing possession

299   of the ball defence could cause increased space through the middle of the ground. This could be

17

300 exploited by employing a higher possession style of play with a slower build-up that reduces the

301 risk of losing possession.

302 　　　　Collective team behaviour investigations in football have revealed that a more defensive

303 game style is generally employed by preserving players behind the centre of the field (Clemente,

304 Couceiro et al. 2013). However, teams may be inclined to engage in a more offensive game style

305 during home matches compared to away matches by positioning players higher up the field (Lucey,

306 Oliver et al. 2013, Bialkowski, Lucey et al. 2014). Higher ranked football teams may also display

307 a more expansive game style with greater values of length, width, and surface area during the

308 offensive phase of play (Castellano, Álvarez et al. 2013, Castellano and Casamichana 2015).

309 Results from the present study suggest AF teams may undertake a more circumstantial approach

310 in allocating players to achieve certain tasks. Teams may aim to restrict space if the ball is in their

311 D50 and press higher up the field to hold the play in their forward half when the ball is in their

312 F50. Increased variation in player movement also exists during the middle of the ground. However,

313 it is difficult to discern if these types of behaviour are a predetermined game style or if its players

314 adapting to the emergent state of the game. For instance, length, width, and surface area appear to

315 be influenced by match phase, while the x-axis centroid is influenced by field position. As such,

316 an increased time spent in offence may be the cause of a team's increased surface area and not

317 necessarily a premeditated approach to commit to a more expansive game style. In addition, a

318 team's inability to move the ball out of its defensive half may represent why the x-axis centroid is

319 behind centre, instead of a defensive strategy to preserve players closer to their own goal.

320 　　　　Whilst contextual factors provide a more informed understanding of how collective

321 behaviour changes during different game states, it is misleading to solely associate collective

322 behaviour with specific team tactics or game style. The current macroscopic approach determines

18

323   player positioning during a specific match phase or field position to infer game style or team

324   tactics. A more granular approach is required that better reflects the different strategies a team

325   might employ during different situations. Specifically, a microscopic method that determines

326   group structures or formations at each point of time will provide a more representative

327   comprehension of game style. This information should be combined with match events or

328   performance outcomes to better understand the efficacy of various playing styles.

329   Some limitations relating to sample size and amount of teams included in this study should

330   be recognised. The present study analysed the collective team behaviour of one club during a single

331   competitive match. Thus additional research should include multiple clubs throughout several

332   matches to construct a more accurate representation of collective behaviour of AF teams and if

333   any variances between teams exist. Future investigations may also analyse the player movement

334   during various contextual variables to gain a more comprehensive understanding of AF collective

335   team behaviour. Relationships between the observed collective team behaviour from this team and

336   specific strategy or team tactics are not yet known. Future work may also incorporate a more

337   granular approach that includes how collective team behaviour form specific structures in real

338   time. In addition, this analysis should incorporate match events (Corbett, Bartlett et al. 2018) or

339   performance outcomes to provide a more representative understanding of team tactics or game

340   style.

341

342   **CONCLUSION**

343

344   This study investigated the influence of match phase and field position on collective team

345   behaviour in AF, thereby providing a proof of concept for future work in this area. When

19

346 considering field position and match phase, the variation in the *x*-axis centroid could be attributed

347 to the change in field position, while match phase had a greater influence on length, width, and

348 surface area. Players were more inclined to re-position closer to their defensive end to restrict

349 space when the ball was closer to their goal and conversely, press higher up the field when the ball

350 was in their forward half. Future investigations of collective team behaviour in AF should look to

351 measure specific formations and structures continuously. This information, with the combination

352 of match events, may provide a more representative understanding of game style or team tactics.

353

354 **DECLARATION OF INTEREST**

355

356 The authors report no conflicts of interest.

357

358 **REFERENCES**

359

360 Akritas, M. G. (2004). "Heteroscedastioc One-Way ANOVA and Lack-of-Fit Tests." Journal of

361 the American Statistical Association **99**(466): 368-390.

362 Alexander, J. P., B. Spencer, J. K. Mara and S. Robertson (2018). "Collective team behaviour of

363 Australian Rules football during phases of match play." Journal of sports sciences: 1-7.

364 Bartlett, R., C. Button, M. Robins, A. Dutt-Mazumder and G. Kennedy (2012). "Analysing team

365 coordination patterns from player movement trajectories in soccer: methodological

366 considerations." International Journal of Performance Analysis in Sport **12**(2): 398-424.

367 Bialkowski, A., P. Lucey, P. Carr, Y. Yue and I. Matthews (2014). "Win at Home and Draw

368 Away": Automatic Formation Analysis Highlighting the Differences in Home and Away

369   Team Behaviors. 8th Annual MIT Sloan Sports Analytics Conference. Hynes Convention

370   Center.

371   Brewer, C., B. Dawson, J. Heasman, G. Stewart and S. Cormack (2010). "Movement pattern

372   comparisons in elite (AFL) and sub-elite (WAFL) Australian football games using GPS."

373   Journal of science and medicine in sport **13**(6): 618-623.

374   Castellano, J., D. Álvarez, B. Figueira, D. Coutinho and J. Sampaio (2013). "Identifying the effects

375   from the quality of opposition in a Football team positioning strategy." International

376   Journal of Performance Analysis in Sport **13**(3): 822-832.

377   Castellano, J. and D. Casamichana (2015). "What are the differences between first and second

378   divisions of Spanish football teams?" International Journal of Performance Analysis in

379   Sport **15**(1): 135-146.

380   Clemente, F., M. Couceiro, F. Martins and R. Mendes (2013). "An online tactical metrics applied

381   to football game." Research Journal of Applied Sciences, Engineering and Technology

382   **5**(5): 1700-1719.

383   Clemente, F., M. Couceiro, F. Martins, R. Mendes and J. Figueiredo (2013). "Measuring

384   Collective Behaviour in Football Teams: Inspecting the impact of each half of the match

385   on ball possession." International Journal of Performance Analysis in Sport **13**(3): 678-

386   689.

387   Clemente, F., J. Sequeiros, A. Correia, F. Silva and F. Martins (2018). Brief Review About

388   Computational Metrics Used in Team Sports, Springer.

389   Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences. New York, Routledge

390   Academic.

391 Corbett, D. M., J. D. Bartlett, F. O'connor, N. Back, L. Torres-Ronda and S. Robertson (2018).
392   "Development of physical and skill training drill prescription systems for elite Australian
393   Rules football." Science and Medicine in Football **2**(1): 51-57.

394 Corbett, D. M., A. J. Sweeting and S. Robertson (2017). "Weak relationships between stint
395   duration, physical and skilled match performance in Australian Football." Frontiers in
396   physiology **8**.

397 Couceiro, M., F. Clemente, F. Martins and J. Machado (2014). "Dynamical stability and
398   predictability of football players: the study of one match." Entropy **16**(2): 645-674.

399 Dwyer, D. B. and T. J. Gabbett (2012). "Global positioning system data analysis: velocity ranges
400   and a new definition of sprinting for field sport athletes." Journal of strength and
401   conditioning research **26**(3): 818-824.

402 Ensum, J., R. Pollard and S. Taylor (2004). "Applications of logistic regression to shots at goal at
403   association football: Calculation of shot probabilities, quantification of factors and
404   player/team." Journal of Sports Sciences **22**(6): 500-520.

405 Folgado, H., K. A. P. M. Lemmink, W. Frencken and J. Sampaio (2014). "Length, width and
406   centroid distance as measures of teams tactical performance in youth football." European
407   journal of sport science **14 Suppl 1**: S487-492.

408 Frencken, W., K. Lemmink, N. Delleman and C. Visscher (2011). "Oscillations of centroid
409   position and surface area of soccer teams in small-sided games." European Journal of Sport
410   Science **11**(4): 215-223.

411 Garganta, J. (2009). "Trends of tactical performance analysis in team sports: bridging the gap
412   between research, training and competition." Revista Portuguesa de Ciências do Desporto
413   **9**(1): 81-89.

414   Goncalves, B., R. Marcelino, L. Torres-Ronda, C. Torrents and J. Sampaio (2016). "Effects of
415   emphasising opposition and cooperation on collective movement behaviour during football
416   small-sided games." <u>J Sports Sci</u> **34**(14): 1346-1354.

417   Gray, A. J. and D. G. Jenkins (2010). "Match analysis and the physiological demands of Australian
418   football." <u>Sports medicine (Auckland, N Z)</u> **40**(4): 347-360.

419   Lamas, L., J. Barrera, G. Otranto and C. Ugrinowitsch (2014). "Invasion team sports: strategy and
420   match modeling." <u>International Journal of Performance Analysis in Sport</u> **14**(1): 307-329.

421   Lucey, P., D. Oliver, P. Carr, J. Roth and I. Matthews (2013). <u>Assessing team strategy using</u>
422   <u>spatiotemporal data</u>. 19th ACM SIGKDD international conference on Knowledge
423   discovery and data mining, Chicago.

424   Rein, R. and D. Memmert (2016). "Big data and tactical analysis in elite soccer: future challenges
425   and opportunities for sports science." <u>Springerplus</u> **5**(1): 1410.

426   Robertson, S., R. Gupta and S. McIntosh (2016). "A method to assess the influence of individual
427   player performance distribution on match outcome in team sports." <u>J Sports Sci</u> **34**(19):
428   1893-1900.

429   Sampaio, J. and V. Macas (2012). "Measuring tactical behaviour in football." <u>International journal</u>
430   <u>of sports medicine</u> **33**(5): 395-401.

431   Silva, P., P. Aguiar, R. Duarte, K. Davids, D. Araujo and J. Garganta (2014). "Effects of pitch size
432   and skill level on tactical behaviours of Association Football players during small-sided
433   and conditioned games." <u>International Journal of Sports Science & Coaching</u> **9**(5): 993-
434   1006.

23

435 Vilar, L., D. Araújo, K. Davids and Y. Bar-Yam (2013). "Science of winning soccer: Emergent

436   pattern-forming dynamics in association football." <u>Journal of systems science and</u>

437   <u>complexity</u> **26**(1): 73-84.

438 Vincent, W. J. (1999). <u>Statistics in Kinesiology</u>, Champaign.

439 Wisbey, B., P. G. Montgomery, D. B. Pyne and B. Rattray (2010). "Quantifying movement

440   demands of AFL football using GPS tracking." <u>Journal of science and medicine in sport</u>

441   **13**(5): 531-536.

442 Wright, C., S. Atkins, R. Polman, B. Jones and L. Sargeson (2011). "Factors associated with goals

443   and goal scoring opportunities in professional soccer." <u>International Journal of</u>

444   <u>Performance Analysis in Sport</u> **11**(3): 438-449.

445 Yue, Z., H. Broich, F. Seifriz and J. Mester (2008). "Mathematical analysis of a soccer game. Part

446   I: Individual and collective behaviors." <u>Studies in applied mathematics</u> **121**(3): 223-243.

447