

# The influence of collective behaviour on pacing in endurance competitions

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AR: Devising and drafting the study, and revising it critically for the intellectual content

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### *Abstract*

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A number of theoretical models have been proposed to explain pacing strategies in individual competitive endurance events. These have typically related to internal regulatory processes informing the making of decisions relating to muscular work rate. Despite a substantial body of research investigating the influence of collective group dynamics on individual behaviours in various animal species, this issue has not been comprehensively studied in individual athletic events. This is surprising given that athletes directly compete in close proximity to one another, and that collective behaviour has also been observed in other human environments. Whilst reasons for adopting collective behaviour are not fully understood, it is thought to result from individual agents following simple local rules resulting in seemingly complex large systems acting to confer some biological advantage to the collective as a whole. Although such collective behaviours may generally be beneficial, endurance events are complicated by the fact that increasing levels of physiological disruption as activity progresses may compromise the ability of individuals to continue to interact with other group members. This could result in early fatigue and relative underperformance due to suboptimal utilisation of physiological resources by some athletes. Alternatively, engagement with a collective behaviour may benefit all due to a reduction in the complexity of decisions to be made and a subsequent reduction in cognitive loading and mental fatigue. This paper seeks evidence for collective behaviour in previously published analyses of pacing behaviour and proposes mechanisms through which it could potentially be either beneficial, or detrimental to individual performance.

### *Ethics statement*

(Authors are required to state the ethical considerations of their study in the manuscript including for cases where the study was exempt from ethical approval procedures.)

*Did the study presented in the manuscript involve human or animal subjects:* No

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## Abstract

A number of theoretical models have been proposed in recent years to explain pacing strategies observed in individual competitive endurance events. These have typically related to the internal regulatory processes that inform the making of decisions relating to muscular work rate. Despite a substantial body of research which has investigated the influence of collective group dynamics on individual behaviours in various animal species, this issue has not been comprehensively studied in individual athletic events. This is somewhat surprising given that athletes often directly compete in close proximity to one another, and that collective behaviour has also been observed in other human environments including pedestrian interactions and financial market trading. Whilst the reasons for adopting collective behaviour are not fully understood, collective behaviour is thought to result from individual agents following simple local rules that result in seemingly complex large systems that act to confer some biological advantage to the collective as a whole. Although such collective behaviours may generally be beneficial, competitive endurance events are complicated by the fact that increasing levels of physiological disruption as activity progresses may compromise the ability of some individuals to continue to interact with other group members. This could result in early fatigue and relative underperformance due to suboptimal utilisation of physiological resources by some athletes. Alternatively, engagement with a collective behaviour may benefit all due to a reduction in the complexity of decisions to be made and a subsequent reduction in cognitive loading and mental fatigue. This paper seeks evidence for collective behaviour in previously published analyses of pacing behaviour and proposes mechanisms through which it could potentially be either beneficial, or detrimental to individual performance. It concludes with suggestions for future research to enhance understanding of this phenomenon.

## 44 1. Introduction

45 'Pacing' is the term used to describe the distribution of muscular work rate throughout an  
46 exercise bout, and is a fundamental requirement of successful endurance performance (Foster  
47 et al., 1994). A great deal of published research in recent years has investigated the regulatory  
48 mechanisms that allow effective regulation of pacing to be achieved. Although there appears  
49 to be little consensus in the literature with regards to the precise processes involved, the  
50 momentary Rating of Perceived Exertion (Tucker, 2009), the Hazard Score (DeKoning et al.,  
51 2011), and emotion (Baron et al., 2011, Renfree et al., 2012) have all been suggested to be  
52 contributing factors. More recently Smits et al., (2014) and Renfree et al., (2014) have  
53 identified the need for greater consideration of decision-making processes in explaining  
54 observed athletic behaviours. Again, whilst the precise processes remain unclear, several  
55 potential models have been proposed for further investigation. It is apparent, however that  
56 whilst considerable research effort has been invested in enhancing understanding of decision-  
57 making based on internal regulatory processes (Tucker, 2009; Marcora & Staiano, 2010; De  
58 Koning et al., 2011; Smits et al., 2014), less has been placed on the possible influence of  
59 external factors such as the relative presence, or indeed absence of other competitors.  
60 Collective behaviours have been described in a number of non-biological, animal and human  
61 environments, and can be explained by relatively simple laws governing interactions being  
62 followed by individual agents giving rise to complex large systems. The aim of this paper is  
63 to identify the possible mechanisms through which the presence of other competitors might  
64 influence collective group behaviour and therefore individual pacing decisions, and to  
65 propose future research priorities.

## 66 2. Collective behaviour

67 A key feature of most individual competitive endurance events is that athletes race directly  
68 against other competitors, sometimes in individually marked lanes, and at other times within  
69 closer proximity to one another. This may mean that adopted behaviours are heavily  
70 influenced by those displayed by other nearby individuals, a phenomenon that has been  
71 studied extensively in other human and animal models. For example, so called 'herd  
72 behaviour' (Bannerjee, 1992) has been found to occur in numerous situations. The model of  
73 herd behaviour suggests that in complex decision-making environments, the 'easiest'  
74 decision to make is simply to do exactly the same as those who happen to be in close  
75 proximity, or at least those of whom the individual is aware. Complex systems theory  
76 suggests that through individual agents following very simple local rules governing  
77 interactions, it is possible to generate large, seemingly complex patterns characteristic of  
78 biological systems (Wolfram, 1985). Through mathematical modelling, it has been  
79 demonstrated that individual agents following relatively simple rules can explain the  
80 collective motion (using terms such as swarms, schools, flocks, herds, and murmurations) of  
81 various animal species (King and Sumpter, 2012). A key feature of all these collective  
82 behaviours is that they emerge in the absence of any obvious centralised control, but rather  
83 because some localised information originating from neighbours flows through a system and  
84 results in the production of a collective pattern (Giardina, 2008). Although the precise  
85 reasons for the adoption of such behaviours are unknown, it is thought that they may aid in  
86 the avoidance of predation, or else be a mechanism through which useful information, such as  
87 location of food sources, may be conveyed between group members (King and Sumpter,  
88 2012). Herd behaviour has also been displayed by humans in various environments. For  
89 example, in financial markets individual market participants appear to mimic one another,

90 leading to heavy tails in the distribution of stock price variations (Cont and Bouchard, 2000),  
91 whereas self-organising phenomena would appear to explain the ‘flow’ behaviour of  
92 pedestrians (Helbing et al., 2005), whereby the time gap between individuals is influenced by  
93 boundary conditions in corridors and at intersections. This tendency towards collective  
94 behaviour and group formation appears to be based on a collective group memory, whereby  
95 previous history of group structure influences future collective behaviours, and individuals  
96 learn to change spatial positions within a group based on adoption of local ‘rules of thumb’  
97 (Couzin et al., 2002).

98 Interestingly, collective behaviour appears to not only occur in biological systems.  
99 Experimental work by Giomi et al. (2013) demonstrated that brainless ‘bristle-bots’  
100 (constructed from toothbrush bristles and an on-board cell phone vibrator motor) transitioned  
101 to collective swarming and swirling behaviour when confined to a limited area. This finding  
102 may suggest that the formation of collective behaviours is a spontaneous occurrence that  
103 translates into swarm intelligence. However, it must be acknowledged that while many  
104 analyses of collective behaviours have tended to treat individuals as simple interacting  
105 physical units (Giordana, 2015), there are potential limitations to this approach. Specifically,  
106 in biological systems individual behaviours may well derive from complicated biological  
107 processes rather than simple physical laws. Indeed, and in relation to athletic activity, Smits  
108 et al (2014) suggest that in order to fully explain decisions related to pacing in athletic events,  
109 it is necessary to understand how perception and action are coupled in determining behaviour,  
110 therefore suggesting an ecological approach may be required.

### 111 **3. Collective behaviour in sport**

112 At this point it should be emphasised that competitive sporting events differ from most other  
113 human and animal environments in a key respect. Whilst the possible reasons for such  
114 behaviour identified earlier, including avoidance of predation and the sharing of information  
115 relating to the location of food (King and Sumpter 2012), may be expected to benefit the  
116 collective as a whole, in individual endurance events it would seem implausible that  
117 individuals would consciously adopt behaviours that would benefit other rival competitors.  
118 Competitive sporting events may therefore be considered rather artificial environments from  
119 a biological perspective, and the influence of engagement in collective behaviours warrants  
120 investigation. Given the complexity of the internal biological processes and the interactions  
121 between autonomous biological entities, identification of simple rules governing both  
122 individual and collective behaviour in sport environments may be impossible. However, to  
123 our knowledge no study has attempted to identify relative weightings given to external and  
124 internal processes in determining decisions made relating to muscular work rate during  
125 individual competitive endurance events.

126 Although some research has suggested that sports teams should be considered  
127 ‘superorganisms’ whose behaviour results from collective processes (Duarte et al, 2012), less  
128 research is available relating to collective behaviour in self-paced endurance activities.  
129 Undoubtedly any behaviour displayed in such an environment would be complicated by the  
130 fact that performance capacity would be disrupted to a greater or lesser extent as an event  
131 progressed due to increasing physiological disruption. A financial trader or a pedestrian can  
132 ‘follow the herd’ for long periods of time with few biological consequences, whereas a  
133 competitor in an endurance race may initially be able to do so before finding their ability to  
134 continue is compromised through metabolic disturbance. Indeed, in racing cyclists Trenchard  
135 et al., (2014) suggest a peloton exhibits collective behaviour similar to that displayed by  
136 flocking birds or schooling fish. A number of general processes were proposed that explained

137 the formation of large collectives and the separation of individuals or sub-groups from these  
138 during mass start velodrome races. These behaviours may reflect inherent evolved processes  
139 that maximise energy savings during collective activities. In a very recent paper, Trenchard  
140 (2015) goes on to suggest that cyclists display 'protocooperative' behaviour whereby they  
141 engage in cooperative activity. However, once the power outputs required for engaging in  
142 this activity become prohibitive due to continued physiological disruption, athletes can no  
143 longer cooperate, and eventually they become uncoupled from the peloton.

144 The issue of energy savings in cyclists described above may imply that collective behaviour  
145 would be beneficial in endurance sports such as this where speeds are high. Indeed, a paper  
146 by Kyle (1979) suggests that 80-90% of the metabolic cost of cycling is accounted for by the  
147 overcoming of wind resistance, but that cycling in a group reduced power output required at  
148 typical racing speeds by 30%. Trenchard (2010) later suggested that the formation of the  
149 peloton, characteristic of cycle road races, is actually formed in order to maximise collective  
150 energy expenditure. During running, where speeds are considerably lower, Kyle (1979) found  
151 only 4-8% of total energetic expenditure was utilised in the overcoming of wind resistance,  
152 and this was reduced by just 2-4% when running in a group. If collective behaviour is an  
153 evolved characteristic that informs decision-making in a group environments, then we  
154 propose that such behaviour may indeed be detrimental to athletic performance in some  
155 sporting events (such as running races) in which high performance is not generally associated  
156 with any survival advantage (which would be the driver of evolved behaviours). In order to  
157 better understand the influence of collective behaviour on pacing strategy then, it is necessary  
158 to seek evidence for this occurring in running events where it should be less advantageous  
159 from a physiological perspective.

#### 160 **4. Evidence for collective behaviour in competitive endurance events**

161 There already exists some evidence for collective behaviours informing decisions relating to  
162 pacing during endurance events. In elite runners competing in both the World Cross Country  
163 Championships (Esteve Lanao et al., 2014; Hanley, 2014) and the World Marathon  
164 Championship (Renfree & St Clair Gibson, 2013), a common observation was made in that  
165 all runners adopted similar absolute running speeds early in the races, but that runners who  
166 eventually finished behind the leading athletes progressively decelerated. This resulted in  
167 overall 'positive' pacing strategies for the majority of athletes which are characterised by a  
168 second half completed at a slower speed than the first. Such strategies are typically  
169 considered suboptimal for events of this kind of duration (Abbiss & Laursen, 2008). In our  
170 analysis of the World Championship marathon race (Renfree & St Clair Gibson, 2013) we  
171 found the degree of underperformance depended on the athlete's absolute performance  
172 potential as determined by their personal best times over the distance. When all athletes were  
173 split into quartiles based on their eventual finishing position, it was not surprisingly found  
174 that mean personal best speeds of each quartile decreased from the leading athletes to those  
175 who finished towards the rear of the race. However, the degree of 'underperformance'  
176 relative to personal best times also increased as athletes finished further behind the leaders.  
177 This would suggest that the adoption of collective behaviours (i.e. similar starting speeds) at  
178 the outset of the race had greater negative effects on the athletes with lower absolute  
179 performance capacities. Although no measures of physiological responses are available for  
180 this event, it can be speculated that physiological disruption would be greater in those athletes  
181 of lower performance capacity, and that therefore the degree of underperformance in the  
182 latter stages of the race would be greater. This disruption and underperformance may also be  
183 expected to result in higher ratings of perceived exertion and more negative affective  
184 responses. This may explain the findings by Mytton et al., (2015) who demonstrated that

185 medal winning athletes in international running and swimming events displayed greater  
186 increases in speed in the final stages than non-medal winning athletes. This greater  
187 acceleration in pace would be possible as a result of the possession of a greater metabolic  
188 reserve capacity (Swart et al., 2009) in the superior athletes. Konings et al. (2015) also  
189 demonstrated very similar findings in 1500m short track speed skaters, whereby 'top'  
190 finishers were only faster than 'bottom' finishers in the final 5 laps (out of 13.5) in elite level  
191 competitions. However, speed skating races are completed at higher speeds than running  
192 events of the same distance meaning that energy savings from collective behaviour would be  
193 expected to be greater. Despite this, Konings et al. (2015) also found that tactical positioning  
194 during the latter stages of the race was a strong determinant of final finishing position. In this  
195 case then, it may be that the energetic costs of accelerating and overtaking leading athletes  
196 (and thereby skating further on the bends) may prohibit the gaining of positions when overall  
197 speeds are high, even though there may be benefits in avoiding leading earlier in the race.  
198 This example again emphasises the importance of consideration of the behaviour of other  
199 group members on explaining individual behaviours during competitive endurance events.

## 200 **5. Potential influence of collective behaviour on mental fatigue**

201 Although the above may suggest that collective behaviours may ultimately be detrimental to  
202 some individual athletes during events such as running races, it should be acknowledged that  
203 there are also potential benefits. Zouhal et al. (2015) found that drafting behind another  
204 runner improved 3000m running performance without any reduction in energy expenditure or  
205 cardiovascular effort, leading the authors to propose that a pacemaker may act to improve  
206 performance through psychological mechanisms. It should however, be acknowledged that  
207 the data presented in this paper could also be interpreted in a different manner. An increased  
208 running speed at the same level of cardiovascular effort could also imply participants  
209 benefitted from an energy saving provided by drafting. Given that regulation of pace requires  
210 continual decision-making (Smits et al., 2014; Renfree et al., 2014), it may therefore be  
211 suggested that following another athlete may act by reducing the number of decisions to be  
212 made, and therefore decrease cognitive loading. Vohs et al. (2014) have established that the  
213 process of decision-making leads to a subsequent loss of self-control characterised by,  
214 amongst other things, reduced physical stamina and reduced persistence in the face of failure.  
215 Indeed, mental fatigue can be induced by prolonged periods of cognitive activity, and is  
216 associated with impaired exercise tolerance despite it not influencing cardiorespiratory or  
217 metabolic factors (Marcora et al., 2009). Some support for this suggestion that group  
218 membership may be beneficial in endurance events is provided by Hanley (2015) who  
219 analysed pack running in the IAAF World half marathon championships. Those athletes who  
220 ran in packs throughout the race showed smaller decrements in speed than those who did not  
221 do so, or did so only for parts of the race. Those athletes who did run in packs throughout  
222 also demonstrated greater accelerations in pace in the final stages, suggesting either  
223 maintenance of a greater metabolic reserve capacity, or that they had developed lower levels  
224 of mental fatigue. Hanley (2015) went on to suggest that in order to optimise performance,  
225 athletes should identify likely rivals of similar performance capacity in advance of the race  
226 and then aim to run with them as part of their pre-race strategy. There is as yet, however, no  
227 evidence that this is actually a good strategy. If running as part of group is to be effective in  
228 maximising endurance performance, its success or otherwise may therefore depend on the  
229 ability to accurately self-assess performance capacity and also that of other athletes. Any  
230 mismatch between individual physiological capacity and that of the group as a whole will  
231 lead to incomplete realisation of performance capacity

232 In contrast to endurance running races whereby athletes compete directly and in close  
233 proximity to one another, pool based swimming races are completed with athletes in their  
234 own individual lanes, meaning that collective behaviours are impossible. In swimming races  
235 pacing profiles are consistent between competitions, and elite athletes do not appear to vary  
236 their tactics or modify their pacing strategies between events (Skorski et al., 2014). Earlier  
237 work by Skorski et al., (2013) had also demonstrated that swimmers produced faster times in  
238 real than simulated competitions, and that these faster times were achieved through  
239 swimming faster in each intermediate stage rather than adoption of a different overall  
240 strategy. These observations may suggest that when athletes are isolated from their direct  
241 competitors as a result of swimming in their own lane, then the reduced opportunities to  
242 engage in collective behaviour means there is less variation in pacing displayed by athletes of  
243 differing performance levels competing in the same event.

## 244 **6. Future perspectives**

245 We have proposed that the human tendency towards collective behaviours may go some way  
246 to explaining pacing decisions displayed by competitive athletes in some athletic events.  
247 However, athletic events are rather ‘artificial’ from a biological perspective, and therefore the  
248 effects of engagement in such behaviours are uncertain. Although this tendency may be  
249 advantageous in relatively high speed endurance sports whereby energy savings from drafting  
250 are significant (for example cycling), it may actually be detrimental in lower speed activities.  
251 Athletes with inferior physiological capacities will be unable to maintain work-rates set by  
252 superior athletes and consequently suffer both physiological and psychological perturbations.  
253 Indeed, although there is some evidence that athletes in running events of relatively long  
254 duration (cross country and marathon running) may select starting speeds based on those  
255 selected by other competitors, it may be hypothesised that the relative benefit of engagement  
256 in such collective behaviour may be greater in shorter running events whereby potential  
257 energetic savings from drafting are increased. This could result in greater group density, or  
258 slower athletes maintaining contact with faster athletes for a greater fraction of total race  
259 distance. It may also be the case that collective behaviour is less evident in sports where there  
260 is greater separation between athletes in space or else they are to some extent isolated from  
261 one another (for example through competing in their own lanes). Alternatively, it may be  
262 possible that engagement in collective behaviours could be beneficial to performance through  
263 reducing the requirement for continuous decision-making and a subsequent reduction in  
264 mental fatigue, even in activities where energetic savings through drafting are minimal.

265 Further research is required in order to better understand the relative influence of both  
266 internal (physiological) and external (environmental) variables on decision-making regarding  
267 work rate during self-paced competitive, individual endurance activity. This could eventually  
268 lead to the development of strategies that allow athletes to make better pacing decisions that  
269 may optimise physiological capacity. Additional work is also required to increase  
270 understanding of sport specific tactical issues that will allow individual athletes to make  
271 better pacing decisions that maximise their chances of optimising performance potential.

## 272 **Author contributions**

273 AR: Devising and drafting the study, and revising it critically for the intellectual content

274 ECdC: Devising and revising the study critically for the intellectual content

275 LM: Revising the study critically for intellectual content and final approval of the version to  
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