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1 Increased variability of lap speeds differentiate medallists and non-medallists in middle  
2 distance running and swimming events

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4  
5 Original Investigation

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7  
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32 Preferred Running Head

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34 Lap speed variability differentiates medallists

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37 Counts

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39 2670 words in manuscript

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41 259 words in the abstract

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43 2 figures in the manuscript

45 Increased variability of lap speeds differentiate medallists and non-medallists in middle  
46 distance running and swimming events

47

48 Abstract

49 Purpose: Previous literature has presented pacing data of groups of competition finalists. The  
50 aim of this study was to analyse the pacing patterns displayed by medallists and non-  
51 medallists in international competitive 400-m swimming and 1500-m running finals.

52 Methods: Split times were collected from 48 swimming finalists (four 100-m laps) and 60  
53 running finalists (4 laps) in international competitions between 2004 and 2012. Using a cross  
54 sectional design, lap speeds were normalised to whole race speed and compared to identify  
55 variations of pace between groups of medallists and non-medallists. Lap speed variations  
56 relative to the gold medallist were compared for the whole field.

57 Results: In 400-m swimming the medallist group demonstrated greater variation in speed than  
58 the non-medallist group, being relatively faster in the final lap ( $p < 0.001$ ; moderate effect) and  
59 slower in laps one ( $p = 0.03$ ; moderate effect) and two ( $p > 0.001$ ; moderate effect). There were  
60 also greater variations of pace in the 1500-m running medallist group compared to the non-  
61 medallist group with a relatively faster final lap ( $p = 0.03$ ; moderate effect) and slower second  
62 lap ( $p = 0.01$ ; small effect). Swimming gold medallists were relatively faster than all other  
63 finalists in lap 4 ( $p = 0.04$ ) and running gold medallists were relatively faster than the 5<sup>th</sup> to  
64 12<sup>th</sup> placed athletes in the final lap ( $p = 0.02$ ).

65 Conclusions: Athletes that win medals in 1500-m running and 400-m swimming competitions  
66 show different pacing patterns from non-medallists. End spurt speed increases are greater  
67 with medallists, who demonstrate a slower relative speed in the early part of races but a faster  
68 speed during the final part of races compared to non-medallists.

69

70 Keywords:

71 Sports performance; pacing; medallist; middle distance.

72

73

74 Introduction

75

76 Pacing is defined as the distribution of effort over an exercise bout<sup>1</sup> to allow for the best  
77 possible completion time for a given activity.<sup>2</sup> Pacing patterns have been shown to have  
78 faster initial and final lap pace in 1 mile running world record events with 30 of the 32 world  
79 record times showing an ‘end spurt’<sup>3</sup> which has been identified as being between 1200-  
80 1300m of the race.<sup>4</sup> Compared to 1500-m running, a milder end-spurt has been reported in  
81 400-m swimming<sup>5</sup> with a fast start that may be accounted for by the dive and 15m underwater  
82 stroke.<sup>6,7</sup> Comparisons between 1500-m running and 400-m swimming do not exist in the  
83 literature but may be useful to contrast pacing patterns of middle distance events with similar  
84 net energetics. The current 400-m men’s freestyle swimming world record is 220.07s<sup>8</sup> and the  
85 current 1500-m men’s running world record is 206.0s,<sup>9</sup> suggesting that the energetics of both  
86 events are similar and derived primarily from the aerobic energy system.<sup>10,11</sup>

87

88 Recently modelled performances of 800-m runners, 200-m swimmers and 1500-m speed  
89 skaters demonstrate that pacing patterns are different for these events despite very similar net  
90 energetic requirements.<sup>12</sup> A key aspect of this research was the development of models that  
91 include the forces of drag and friction which differ between skating, running and swimming.  
92 The study recommended that 200-m swimmers, who experienced the highest drag, keep to an  
93 even pace whereas 800-m runners should start faster. There is some evidence to suggest that  
94 in running, although the ability to achieve a fast overall time is important, so is tactical  
95 positioning throughout the race.<sup>13</sup> Similarly tactical positioning at intermediate stages of  
96 middle distance races was found to be a significant factor in finishing position at the  
97 London Olympic Games.<sup>14</sup> In swimming athletes are not in close physical proximity so  
98 pacing patterns should focus on an optimal individual performance<sup>15</sup> although there could be  
99 some tactical advantages in drafting behind a competitor<sup>16</sup> whilst avoiding waves created by  
100 them.<sup>17</sup>

101

102 There have been calls for high level competition data to be used to investigate pacing in the  
103 real world and outside of laboratory conditions.<sup>14,18</sup> An investigation into pacing differences  
104 in world class middle distance competitions would add to the theoretical basis developed by  
105 others for shorter events.<sup>12</sup> In a recent review article,<sup>15</sup> many examples of parabolic pacing  
106 patterns in longer duration events were reported, however the difference between medallists  
107 and non-medallists was not investigated. Whilst some literature has identified differences in  
108 pacing profiles based on finishing position by splitting finishers into quartiles<sup>13</sup> or by  
109 comparing groups of finalists and semi-finalists<sup>5</sup>, there is a need to define pacing patterns that  
110 are successful enough to win a medal which is often the target for elite athletes and their  
111 funding agency. This information could be used by coaches and athletes in these events when  
112 preparing training strategies and racing plans. Therefore the aim of this study was to analyse  
113 the pacing patterns displayed by medallists and non-medallists in international competitive  
114 400-m swimming and 1500-m running finals.

115

116 Methods

117

118 Data Collection

119

120 Data were collected from international competitions between 2004 and 2012 in men’s 400-m  
121 swimming and 1500-m running events. In total 48 performances were analysed from six  
122 international 400-m freestyle swimming final competitions which is one more event than has  
123 previously been reported as being needed to ensure reliability.<sup>19</sup> 50m split times from the

124 final in each championship were included from the European Championships in 2006, 2010  
125 and 2012, the World Championships in 2007 and 2011 and the Commonwealth Games in  
126 2006. Data was freely available in the public domain from the Omega Timing results service  
127 ([www.omegatiming.com](http://www.omegatiming.com)) and was anonymised before publication. Due to effects of full body  
128 swim suits on speed<sup>20</sup> a preliminary assessment of data from events in 2008 and 2009 when  
129 polyurethane suits were legal was carried out. This suggested that pacing patterns were  
130 altered, in particular a significantly faster 3<sup>rd</sup> lap was seen during these years (absolute mean  
131 time  $57.24 \pm 0.75$  with a polyurethane suit vs.  $57.75 \pm 0.59$  s with a standard suit;  $p=0.02$ )  
132 and therefore data from the 2008 Olympics and the 2009 World Championships were  
133 excluded, despite others finding no interaction between pacing pattern and suit use.<sup>6</sup> For  
134 1500-m running, video recordings were obtained from public websites of 5 athletics final  
135 events which is the number of events reported to ensure a reliable sample<sup>19</sup>. Videos were  
136 included from the 23<sup>rd</sup> and 24<sup>th</sup> Olympiads (Athens 2004 and Beijing 2008), the International  
137 Association of Athletics Federations (IAAF) World Championships in 2009 and 2005, and  
138 the European Athletics Championships in 2010. Videos were only used when a static camera  
139 view of the start/finish line existed as athletes crossed the line on every lap during the final of  
140 the 1500-m event. In total 60 performances were analysed from these five events. A static  
141 camera view of the start/finish line was not available for the IAAF 2011 or 2007 World  
142 Championships or the European Athletics Championships in 2006. The videos were uploaded  
143 into Dartfish TeamPro v5 (Dartfish, Switzerland) and each athlete's lap times measured using  
144 a frame by frame playback method.<sup>21</sup>

145

#### 146 Ethical Approval

147

148 The data used were obtained from publicly available websites and therefore ethical approval  
149 to collect secondary data was given by the Northumbria University Health & Life Sciences  
150 ethics committee. All data was anonymised upon addition to the database and it was ensured  
151 that no individuals could be identified from the reporting of the results.

152

#### 153 Data Analysis

154

155 Lap times for both running and swimming events were divided by the lap distance to provide  
156 lap speed ( $\text{m}\cdot\text{s}^{-1}$ ). Overall race speed was calculated so that each lap speed could be expressed  
157 as a percentage of the overall race speed, also known as normalised speed<sup>7</sup>. Lap speeds for  
158 100-m portions of the 400-m swimming race are presented to allow for easy comparison to  
159 1500-m running. Lap speeds in both running and swimming were not normally distributed.  
160 Normalised speed for each lap in medallists and non-medallists were compared using a Mann  
161 Whitney test. Lap times relative to the gold medallist were compared for each finishing  
162 position using a Kruskal-Wallis tests for each lap and followed up where necessary by Mann  
163 Whitney tests to isolate differences between the gold medallist and the rest of the field.  
164 Statistical significance was set at  $p<0.05$ . Cohens  $d$  effect size was calculated for all  
165 significant differences using the pooled standard deviation as the denominator and the  
166 difference between group means as the numerator.<sup>22</sup> Effect size was classified as trivial  
167 ( $<0.2$ ), small ( $>0.2-0.6$ ), moderate ( $>0.6-1.2$ ) and large ( $>1.2-2.0$ ).<sup>23</sup>

168

#### 169 Results

170

171 The normalised speeds for medallist and non-medallist groups in each lap and sport are  
172 described in figure 1. Medallists in 1500-m running had greater variation in speed than non-  
173 medallists with a faster lap four ( $110.2 \pm 2.8\%$  vs.  $107.9 \pm 3.5\%$ ,  $p = 0.03$ ,  $d = 0.70$  moderate)

174 and slower lap two ( $92.7 \pm 1.8\%$  vs.  $93.8 \pm 2.1\%$ ,  $p = 0.01$ ,  $d = 0.54$  small). In absolute terms  
175 medallists were  $0.22 \text{ m}\cdot\text{s}^{-1}$  faster in lap four and  $0.01 \text{ m}\cdot\text{s}^{-1}$  slower in lap two. In laps one and  
176 three the normalized speed of the medallist and non-medallist groups did not differ from each  
177 other (lap one  $96.9 \pm 3.1\%$  vs.  $98.1 \pm 3.5\%$ ,  $p = 0.13$ ; lap three  $101.3 \pm 3.4\%$  vs.  $102.0 \pm$   
178  $3.2\%$ ,  $p = 0.28$ ) and absolute speeds were  $0.01 \text{ m}\cdot\text{s}^{-1}$  and  $0.02 \text{ m}\cdot\text{s}^{-1}$  faster in the medallists in  
179 these laps respectively. In 400-m swimming the medallist group also had greater variation in  
180 speed than the non-medallists group. The medallists in swimming had a faster normalized  
181 speed in lap four ( $101.8 \pm 1.7\%$  compared to  $100.5 \pm 1.2\%$ ,  $p \leq 0.01$ ,  $d = 0.93$  moderate) than  
182 non-medallists and relatively slower speeds in laps one ( $102.2 \pm 1.2\%$  compared to  $103.1 \pm$   
183  $1.1\%$ ,  $p = 0.03$ ,  $d = 0.75$  moderate) and two ( $97.7 \pm 0.8\%$  compared to  $98.2 \pm 0.6\%$ ,  $p <$   
184  $0.001$ ,  $d = 0.78$  moderate). Normalized speed in swimming was not different between the  
185 groups in lap three ( $98.5 \pm 1.0\%$  vs.  $98.4 \pm 0.6\%$ ,  $p = 0.63$ ). Comparison of the absolute  
186 speeds in these laps show that medallists were  $0.01 \text{ m}\cdot\text{s}^{-1}$ ,  $0.01 \text{ m}\cdot\text{s}^{-1}$ ,  $0.02 \text{ m}\cdot\text{s}^{-1}$  and  $0.05 \text{ m}\cdot\text{s}^{-1}$   
187 faster during laps 1, 2, 3 and 4 respectively. Lap speed varied to a greater extent in running  
188 medallists (with a range of 91- 115% of overall pace) compared to swimming medallists (a  
189 range of 97-105% of overall pace).

190

191 *Figure 1 near here.*

192

193 In 1500-m running there were significant differences in speed in lap four between finishing  
194 positions when calculated relative to the gold medallist ( $p < 0.01$ ), but no differences were  
195 observed in laps one, two or three (Figure 2). Post hoc analysis identified that positions 5 to  
196 12 had significantly lower speed relative to the gold medallist on lap four ( $p = 0.02$  to  $0.005$ )  
197 and on average were  $0.26 \text{ m}\cdot\text{s}^{-1}$  slower than gold medallists in absolute speed. In swimmers  
198 there were no differences in speed relative to the gold medallist in lap one, however there  
199 were differences in laps two, three and four ( $p = 0.02$ ,  $0.002$  and  $\leq 0.01$  respectively, Figure  
200 2). Post hoc analysis show that gold medallists were significantly faster than 6th to 8th place  
201 on lap two ( $p = 0.04$  to  $0.002$ ;  $0.01 \text{ m}\cdot\text{s}^{-1}$  faster on average), 4th to 8th place on lap three ( $p =$   
202  $0.04$  to  $0.002$ ;  $0.02 \text{ m}\cdot\text{s}^{-1}$  faster on average) and 2nd to 8th place on lap four ( $p = 0.04$  to  
203  $0.002$ ;  $0.06 \text{ m}\cdot\text{s}^{-1}$  faster on average). It was also found that silver medallists were significantly  
204 faster than the gold medallists on lap 2 ( $p = 0.04$ ) by  $0.01 \text{ m}\cdot\text{s}^{-1}$ .

205

206 *Figure 2 near here.*

207

## 208 Discussion

209

210 The main finding of this study is that performance in the final lap in 1500-m running and  
211 400-m swimming can differentiate between medallists and non-medallists. The last lap  
212 showed the largest differences in absolute, normalized and relative speed between the  
213 medallists and non-medallists. The success associated with a more pronounced end-sprint in  
214 both disciplines suggests that medallists were able to call on reserves of energy not available  
215 to non-medallists three-quarters of the way through the race. This may have been possible  
216 due to a lower physiological disturbance in the medallists at this stage of the race which in  
217 turn may be due to their faster  $\text{VO}_2$  kinetics, a greater critical speed and possibly a greater  
218 aerobic capacity, meaning they produce a slower rise in the slow component and take longer  
219 to attain their  $\text{VO}_{2\text{max}}$ .<sup>24</sup>

220

221 Our findings show that the pacing pattern which characterises a winning race performance is  
222 different to that which characterises a world record performance as improvements in the 1-  
223 mile male running world record has been attributed to a relatively more even pacing pattern.<sup>25</sup>

224 This may be an effect of the use of pace-makers who are often deployed in world record  
225 attempts. In swimming, the end-spurt seen in this study was pronounced and saw gold  
226 medallists on average swim a faster final 100-m than first 100-m including the dive start  
227 whilst all other finishing positions averaged a slower final 100-m than their first 100-m. Gold  
228 medal swimmers were significantly faster than all other swimmers during the final lap. In  
229 separating swimmers by finishing position, the current study has added to previous work<sup>5</sup>  
230 finding a greater 'end-spurt' in medallists and showing that this differentiates them from non-  
231 medallists (the lap four speed of the medallists increased from the previous lap by 1.2% more  
232 than the speed increase in non-medallists at the same point in the race). In both events a more  
233 conservative initial speed that allowed for increases later on appears to be associated with  
234 success, however athletes will need mental confidence and physical talent in order to put  
235 these strategies into practice.

236  
237 International 400-m swimmers demonstrated a u-shaped speed curve<sup>26</sup> during the  
238 competitions analysed. The fast start can be accounted for by the dive start and underwater  
239 component where speeds of over  $3.5\text{m}\cdot\text{s}^{-1}$  can be achieved from a grab dive start,<sup>27</sup> twice the  
240 average race speed seen in this study. In international competition swimming medallists,  
241 particularly gold medallists, seem to exhibit a different pacing pattern during finals than non-  
242 medallists which disagrees with others who report similar patterns for 400-m swimming  
243 finalists albeit with small individual differences.<sup>5,28</sup> In swimmers in this study the medallists  
244 were swimming below their mean velocity in the first half of their race whereas non-  
245 medallists were swimming above it indicating the importance of having the ability to increase  
246 speed at the end of the race as suggested previously.<sup>29</sup> The first half of the race may be the  
247 time when more successful swimmers conserve energy and spare their anaerobic capacity for  
248 use later on and by doing so may help them to better finishing positions.<sup>30</sup> Conversely those  
249 swimmers who swim faster over the initial stages seem unable to sustain the necessary speed  
250 to compete for medal positions in the latter race stages.

251  
252 The 1500-m runners demonstrated a j-shaped speed curve,<sup>26</sup> speeding up in laps three and  
253 four after slowing in lap two, which is similar to previous literature for the same race  
254 distances.<sup>3,4</sup> Absolute and relative speeds in lap four were higher than all other laps for each  
255 finishing position emphasising the importance of final lap speed for every finisher in this  
256 event. Running performances showed greater variation in lap speed during a race compared  
257 to swimmers as previously found.<sup>19</sup> All runners had a greater relative speed in the second half  
258 of the race compared to swimmers. The swimmers had a greater relative speed in the first half  
259 than runners and overall produced a more evenly paced pattern during races. Runners share  
260 the same lane and therefore are more concerned with tactical considerations,<sup>14</sup> drafting  
261 benefits<sup>31</sup> and their opponents' pace, whereas swimmers are able to adopt a more consistent<sup>19</sup>  
262 self-selected race pattern, are less spatially affected by their opponents and are exposed to  
263 greater drag forces as speeds in the water increase.<sup>32</sup>

264  
265 The current study employed independent statistical tests even though some individual athletes  
266 appear in more than one finishing position in different races. Athletes with more than one  
267 appearance were removed from the data set to see if this would affect the findings however  
268 only minor differences were found in the analysis of normalised lap speeds between medallist  
269 and non-medallist groups and there were no differences in the relative to gold medallists  
270 analysis. It was thought that it was more ecologically valid to include all athletes to ensure  
271 that the lap speeds for each finishing position were as complete as possible. Independent  
272 statistics are also less likely to produce a type I error than dependent statistics and as such are  
273 a more conservative option. This study included data from one race per calendar year from

274 the Olympic, World or European championships to try and ensure that the pacing patterns  
275 described were indicative of those at the highest level of performance. It is acknowledged  
276 therefore that competitive elite level performances in other competitions were not included  
277 for comparison from the 2004-2012 period and may show alternative pacing patterns.

278

#### 279 Practical applications to coaches and athletes.

- 280 • Athletes in 400-m swimming and 1500-m running events need to be able to increase  
281 their speed during the final lap of the race to maximise their chances of winning gold.
- 282 • As long as athletes stay in touch with their opponents, adopting a conservative speed  
283 in the early stage of 400-m swimming and 1500-m running finals might result in a  
284 more successful race performance because absolute speed can be increased by a  
285 greater margin in the final lap.

286

287

#### 288 Conclusion

289

290 Previous research has used international competitive data to show pacing profiles adopted by  
291 international finalists, information which is useful for aspiring athletes. This study extends  
292 this approach by showing how pacing patterns can differentiate between successful and  
293 unsuccessful finalists in terms of medal success. To win a medal in both 400-m swimming  
294 and 1500-m running it appears necessary to vary pace during the race by adopting a more  
295 conservative pace in the early stages to allow for a relatively greater increase in speed at the  
296 end of the race.

297

298

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302

303



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380 Figure Headings

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382 Figure 1: Differences between sports in normalised speed for medallists and non-medallists in  
383 1500-m running and 400-m swimming. \* Medallists significantly faster than non-medallists;  
384 # Non-medallists significantly faster than medallists.

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386 Figure 2: Lap times relative to the gold medallist for each lap in the 1500-m run and 400-m  
387 swim.

388 \*Significantly slower than the gold medallist; # significantly faster than the gold medallist.

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