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### **Paper:**

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1 *Title:* Alterations to the orientation of the ground reaction force vector affect sprint acceleration  
2 performance in team sports athletes

3

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12

13 *Running title:* GRF orientation and acceleration performance

14

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16

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24

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28 *Abstract:*

29 A more horizontally oriented ground reaction force vector is related to higher levels of sprint  
30 acceleration performance across a range of athletes. However, the effects of acute experimental  
31 alterations to the force vector orientation within athletes is unknown. Fifteen male team sports  
32 athletes completed maximal effort 10 m accelerations in three conditions following different verbal  
33 instructions intended to manipulate the force vector orientation. Ground reaction forces were  
34 collected from the step nearest 5 m and stance leg kinematics at touchdown were also analysed to  
35 understand specific kinematic features of touchdown technique which may influence the  
36 consequent force vector orientation. Magnitude-based inferences were used to compare findings  
37 between conditions. There was a likely more horizontally oriented ground reaction force vector and  
38 a likely lower peak vertical force in the control condition compared with the experimental  
39 conditions. 10 m sprint time was very likely quickest in the control condition which confirmed the  
40 importance of force vector orientation for acceleration performance on a within-athlete basis. The  
41 stance leg kinematics revealed that a more horizontally oriented force vector during stance was  
42 preceded at touchdown by a likely more dorsiflexed ankle, a likely more flexed knee, and a  
43 possibly or likely greater hip extension velocity.

44 *Introduction*

45 Sprint acceleration is a fundamental component of team sports (Duthie, Pyne, Marsh, & Hooper,  
46 2006; Varley & Aughey, 2013). This ability to rapidly increase whole body velocity is often  
47 measured as the time taken to cover a short distance from a stationary position. Effective  
48 acceleration requires the generation of large ground reaction forces (GRFs) in ground contact  
49 times typically less than 200 ms (Rabita et al., 2015), and physical capabilities such as concentric  
50 strength and power have thus been shown to be related to sprint acceleration performance in team  
51 sports athletes (Cunningham et al., 2013; McBride et al., 2009; Sleivert & Taingahue, 2004).  
52 However, these relationships are typically only moderately strong and the remaining variation in  
53 sprint acceleration performance is seldom further explained by additional physical capabilities  
54 (Cronin & Hansen, 2005; Cunningham et al., 2013; Sleivert & Taingahue, 2004).

55

56 Recent evidence suggests that some or all of the additional variation in sprint acceleration  
57 performance could be explained by technical ability. Descriptive and regression-based studies  
58 demonstrate that higher performing accelerators within similar participant groups (the analysed  
59 groups range between studies from physical education students to elite sprinters) do not produce  
60 greater magnitudes of resultant GRF, instead they direct the resultant GRF vector in a more  
61 horizontal direction (Kawamori, Nosaka, & Newton, 2013; Kugler & Janshen, 2010; Morin,  
62 Edouard, & Samozino, 2011; Rabita et al., 2015; Slawinski et al., 2016). This technical ability has  
63 been quantified by calculating the ratio of forces (RF; Morin et al., 2011) which expresses the  
64 horizontal (antero-posterior) component of the GRF vector as a percentage of the total (two-  
65 dimensional) GRF vector magnitude. These studies suggest that provided sufficient GRF  
66 magnitude can be produced, at broadly similar performance levels the technical ability of producing  
67 a higher RF is of greater importance than the physical capability of producing larger GRFs for  
68 sprint acceleration performance. However, whilst the importance of this higher RF has been  
69 demonstrated between participants in group-based and cross-sectional studies, experimental  
70 within-participant research is required to strengthen the case for a causal relationship (Bishop,  
71 2008).

72

73 In order to acutely manipulate RF within-participants, aspects of sprint acceleration technique  
74 which potentially underlie it must be identified. This would not only allow an experimental study to  
75 be effective in acutely manipulating RF, it could also provide novel insight regarding specific  
76 kinematic features of technique which could be targeted to affect RF. Although specific features of  
77 technique which underlie the ability to produce a high RF remain unclear, existing sprint  
78 acceleration research provides some direction. Slawinski et al. (2016) found that the use of  
79 different start positions affected RF during the initial push-off phase from stationary, but RF was  
80 not reported from the subsequent steps. Jacobs and van Ingen Schenau (1992) analysed the  
81 second stance phase of a maximal effort sprint and identified a general lower-body strategy in  
82 which highly-trained sprinters delayed extension of the centre of mass (CM) away from the centre  
83 of pressure until they had first rotated the CM further forwards. This yielded a greater horizontal  
84 component of the subsequent extension of the CM away from the centre of pressure, more  
85 favourable given the horizontal translational demands of sprint acceleration. Kugler and Janshen  
86 (2010) analysed the first stance phase of physical education students from both a standing start  
87 and the second or third accelerative stance following a flying start. They found the CM of the higher  
88 performing accelerators within the group to be further forward relative to their centre of pressure  
89 when averaged over stance compared with the lower performing half of the cohort. These superior  
90 accelerators achieved this by placing their stance foot further back relative to their CM at  
91 touchdown or by prolonging ground contact time. This alteration in lower body kinematics at  
92 touchdown directly impacts the strategy outlined by Jacobs and van Ingen Schenau (1992); if the  
93 stance foot is further back relative to the CM at touchdown then less forwards rotation is required  
94 before extension can contribute to a given horizontal translation of the CM. Such a strategy was  
95 recently theoretically confirmed using a computer simulation of a sprinter during the first stance  
96 phase whereby systematically placing the foot further back at touchdown relative to the CM led to a  
97 near linear increase in RF during the ensuing stance phase (Bezodis, Trewartha, & Salo, 2015).  
98 Finally, in one of the few within-participant comparisons of sprint acceleration to date, where trials  
99 with high and low braking forces at 16 m were compared within individuals among a group of 36  
100 track and field and team sports athletes (Hunter, Marshall, & McNair, 2005), the stance foot was  
101 less far ahead of the CM at touchdown in the trials with lower braking impulses.

102

103 The placement of the stance foot relative to the CM at touchdown appears to be a potentially  
104 important feature of technique during sprint acceleration. However, it must be considered that the  
105 stance leg is multi-segmental and therefore the relative location of the stance foot is primarily  
106 determined by the angles of the stance hip, knee and ankle joints. Furthermore, in addition to  
107 landing with the stance foot less far ahead of the CM to exaggerate the strategy outlined by Jacobs  
108 and van Ingen Schenau (1992), this strategy could also be exaggerated by rotating the CM ahead  
109 of the stance foot more rapidly. The angular velocity with which the hip, knee and ankle are rotating  
110 at touchdown may therefore be another kinematic feature of technique of interest. In addition to  
111 solely considering the placement of the stance foot relative to the CM, investigation of the stance  
112 leg joint angles and angular velocities at touchdown could provide valuable insight regarding more  
113 specific kinematic features of technique which may be important for achieving a high RF. We  
114 therefore aimed to acutely manipulate the ratio of forces produced by team sport athletes during  
115 acceleration and identify how this affected overall sprint acceleration performance, and to identify  
116 and understand any kinematic features of technique associated with a higher ratio of forces.

117

118

### 119 *Methods*

120 The study was approved by the University Research Ethics Committee and 18 male team sport  
121 (Gaelic football, rugby union, soccer) athletes (mean  $\pm$  SD: age = 22  $\pm$  4 years, mass = 78.2  $\pm$   
122 10.5 kg, height = 1.76  $\pm$  0.10 m) provided written informed consent to participate. Participants  
123 completed three 10 m sprints from a standing start in each of three counterbalanced conditions.  
124 Given the widespread use of verbal technical instructions in sprint coaching, different verbal  
125 instructions were provided immediately prior to each sprint in an attempt to manipulate ratio of  
126 forces between the three conditions. These instructions were based on the well-established motor  
127 learning manipulation of attentional focus (see Wulf, 2013 for a review) where internally and  
128 externally focussed instructions are used to direct a performer's attention towards either their  
129 movements (internal focus) or the effect of these movements on the environment (external focus).  
130 Attentional focus research has consistently demonstrated that manipulating verbal instructions is

131 an effective means through which to acutely alter technique and performance outcome (Wulf,  
132 2013), including during maximal effort vertical and horizontal jumping (Porter, Ostrowski, Nolan, &  
133 Wu, 2010; Wulf & Dufek, 2009) where GRF production is a key determinant of performance, as it is  
134 for sprint acceleration.

135

136 In all conditions, participants were instructed to "complete the 10 m sprint as quickly as possible".  
137 No further instructions were given in the control condition. For the internal focus condition, the  
138 instructions continued with "whilst focussing on pulling your leg backwards just before each contact  
139 with the ground". For the external focus condition, the instructions continued with "whilst focussing  
140 on clawing backwards at the ground with your shoe in every step you take". These instructions  
141 were designed to affect lower-limb action at touchdown in line with our rationale. They were based  
142 on the recommendations of Wulf (2013) in that they were purposefully similar in content and  
143 amount of information provided, focussed on the same aspect of the movement, and only differed  
144 in whether attention was directed internally (the leg) or externally (the ground). As proposed by  
145 Peh, Chow and Davids (2011), all participants completed a written manipulation check after each  
146 condition to verify whether their self-reported attentional focus matched that of the intended  
147 experimental condition. Qualitative analysis of these data led to the removal of three participants  
148 who reported attentional foci which conflicted with one or more of the intended experimental  
149 conditions (i.e. n = 15 for all subsequent quantitative analyses). Participants were not provided with  
150 augmented feedback at any time; they were unaware of their sprint times and were given no  
151 feedback regarding their movements.

152

153 All sprints were completed in a 30 m indoor laboratory in training shoes on a rubber track following  
154 a self-directed warm-up. All sprints were initiated by the participant and commenced from a  
155 standing two-point start with one foot ahead of the other just behind a set of timing lights (TC  
156 Timing System, Brower, USA). A second set were located 10 m away to determine sprint  
157 acceleration performance. Where necessary, the exact location of both timing lights was adjusted  
158 slightly (the exact distance between them always remained at 10 m) to ensure that complete GRFs  
159 from the ground contact closest to the 5 m mark were recorded (960 Hz) from an embedded 0.9 ×



160 0.6 m force platform (9287BA, Kistler, Switzerland) without any targeting from the participants. For  
161 some athletes, up to five sprints were required in a given condition to successfully obtain GRF data  
162 for three sprints. Thirty-eight reflective markers were attached to each participant at specific  
163 locations. Markers at the anterior and posterior superior iliac spines, greater trochanters, medial  
164 and lateral aspects of the knee joint centre, medial and lateral malleoli, and first and fifth  
165 metatarsal-phalangeal joint centres were used to define the seven segments (pelvis, 2 × thigh, 2 ×  
166 shank, 2 × foot) from a static trial. Additional markers (in clusters on the thighs and shanks) were  
167 also attached for this static trial and were subsequently used to track these segments using a  
168 CAST approach (Cappozzo, Catani, Della Croce, & Leardini, 1995) during the sprint acceleration  
169 trials. Marker trajectories were tracked (240 Hz) using an 11-camera motion capture system (MX-3,  
170 Vicon, UK) and collected alongside synchronous GRF data using Nexus (v. 1.8.5, Vicon, UK). The  
171 raw marker trajectories were labelled in Nexus before all data were exported for analysis in  
172 Visual3D (v. 5.01, C-Motion Inc., USA).

173

174 Marker trajectories were low-pass filtered using a 4<sup>th</sup> order Butterworth digital filter at 20 Hz and  
175 segmental kinematics were reconstructed from the tracking markers using an evenly-weighted  
176 inverse kinematics procedure (Lu & O'Connor, 1999). For the ground contact on the force platform,  
177 touchdown and toe-off were identified from the raw vertical GRF data (10 N threshold) and  
178 flexion/extension angles (Cardan X-Y-Z, expressed relative to the static trial in neutral standing)  
179 and angular velocities (resolved in the proximal segment) were calculated and identified at  
180 touchdown. Where touchdown occurred between frames of kinematic data, linear interpolation was  
181 used to obtain a closer representation of the true touchdown value. The antero-posterior velocity of  
182 the stance foot CM at touchdown was extracted as foot touchdown velocity, and the antero-  
183 posterior distance between the stance foot CM and the pelvis CM at touchdown was calculated  
184 (hereafter termed touchdown distance; a positive value represents foot ahead of pelvis). Peak and  
185 average GRFs during stance were identified and divided by body weight, and impulses were  
186 determined using the trapezium rule and divided by body mass to yield changes in velocity. Ratio  
187 of forces was calculated using the previously described procedures of Morin et al. (2011). Toe-off  
188 from the stance phase prior to that on the force platform was determined when the vertical position

189 of the 5<sup>th</sup> metatarsal-phalangeal marker first exceeded 0.1 m (Lees, Steward, Rahnama, & Barton,  
190 2009), and flight time from this step was determined. Step length for this step was calculated from  
191 the antero-posterior coordinates of the 5<sup>th</sup> metatarsal-phalangeal markers at adjacent toe-off  
192 events.

193

194 For all dependent variables, the mean value for each participant was calculated from the three  
195 trials for each condition. A repeated measures ANOVA was conducted for each dependent variable  
196 to identify whether a significant ( $p < 0.05$ ) main effect of experimental condition was present. For  
197 all variables where a significant main effect was observed, the pairwise differences were then  
198 analysed using a magnitude-based inference approach (Batterham & Hopkins, 2006; Hopkins,  
199 2006). Effect size statistics (Cohen's  $d$ ; Cohen, 1988) were calculated between each of the three  
200 pairs of conditions, and 97% confidence intervals (to remain conservative due to three pairwise  
201 comparisons) were calculated to quantify the uncertainty of these effect sizes (Hopkins, 2006). The  
202 smallest worthwhile change was determined as an effect size of 0.2 (Hopkins, 2004; Winter, Abt, &  
203 Nevill, 2014) which also standardised the interpretation between variables in different units. This  
204 allowed the percentage likelihood that each effect was negative, trivial, and positive to be  
205 determined, from which qualitative, mechanistic magnitude-based inferences were made (Hopkins,  
206 2006).

207

208

## 209 *Results*

210 There was a significant main effect of experimental condition on RF and sprint acceleration  
211 performance (i.e. 10 m sprint time; Table 1). Ratio of forces was likely lower (i.e. a more vertically  
212 directed GRF vector) in both the internal and external focus conditions compared with the control  
213 condition (by  $1.7 \pm 1.7\%$  and  $1.3 \pm 1.1\%$ , respectively (mean  $\pm$  97% confidence interval)), whilst the  
214 difference between the internal and external focus conditions was unclear (Figure 1a, Table 2).  
215 The 10 m sprint times were very likely longer (i.e. a lower level of performance) in both the internal  
216 and external focus conditions compared with the control condition (by  $0.056 \pm 0.036$  s and  $0.056 \pm$   
217  $0.042$  s, respectively), whilst the difference between the internal and external focus conditions was

218 unclear (Figure 1b, Table 2). When looking in greater detail at the GRF data, there was no  
219 significant main effect of experimental condition on the peak or average resultant force or its  
220 horizontal component but there was a main effect on the peak vertical GRF magnitude (Table 1).  
221 Peak vertical GRF was very likely greater in the internal focus condition compared with the control  
222 condition (by  $0.17 \pm 0.10$  BW), likely greater in the external focus condition compared with the  
223 control condition (by  $0.09 \pm 0.08$  BW), and possibly smaller in the external focus condition  
224 compared with the internal focus condition (by  $0.08 \pm 0.09$  BW; Figure 1c, Table 2). There was no  
225 significant main effect of experimental condition on any of the horizontal impulses (braking,  
226 propulsive or net propulsive) but there was a main effect of condition on vertical impulse (Table 1).  
227 Vertical impulse was very likely greater in both the internal and external focus conditions compared  
228 with the control condition (by  $0.08 \pm 0.07$  m/s and  $0.06 \pm 0.04$  m/s, respectively), whilst the  
229 difference between the internal and external focus conditions was unclear (Figure 1d, Table 2).

230

231 \*\*\*\*Table 1 near here\*\*\*\*

232 \*\*\*\*Table 2 near here\*\*\*\*

233 \*\*\*\*Figure 1 (a-g) near here\*\*\*\*

234

235 Regarding the kinematics at the instant of touchdown, there was a significant main effect on ankle  
236 angle, knee angle and hip angular velocity (Table 1). The ankle was very likely more plantar flexed  
237 at touchdown in the internal focus condition compared with the control condition (by  $3.3 \pm 2.1^\circ$ ),  
238 likely more plantar flexed at touchdown in the external focus condition compared with the control  
239 condition (by  $2.5 \pm 2.2^\circ$ ), whilst the difference between the internal and external focus conditions  
240 was likely trivial (Figure 1e, Table 2). The knee was likely more extended at touchdown in both the  
241 internal and external focus conditions compared with the control condition (by  $2.1 \pm 2.0^\circ$  and  $1.6 \pm$   
242  $1.7^\circ$ , respectively), whilst the difference between the internal and external focus conditions was  
243 unclear (Figure 1f, Table 2). Hip extension angular velocity was likely slower in the internal focus  
244 condition compared with the control condition (by  $49 \pm 39^\circ/\text{s}$ ), possibly slower in the external focus  
245 condition compared with the control condition (by  $33 \pm 49^\circ/\text{s}$ ), and possibly faster in the external  
246 focus condition compared with the internal focus condition (by  $15 \pm 39^\circ/\text{s}$ ; Figure 1g, Table 2).

247 There was no significant main effect of experimental condition on the other investigated joint  
248 angular kinematics at touchdown, nor on touchdown distance, foot touchdown velocity, or the  
249 preceding step length and flight time (Table 1).

250

251

## 252 *Discussion*

253 We aimed to acutely manipulate the ratio of forces produced by team sport athletes and quantify  
254 the effects on sprint acceleration performance, as well as identifying and understanding specific  
255 kinematic features of technique associated with a higher ratio of forces. For all variables where  
256 significant main effects of condition were observed, the internal and external focus conditions both  
257 yielded similar responses compared with the control condition (Table 2). Given the aim of this  
258 study, and the fact that both experimental conditions elicited similar changes in 10 m sprint time,  
259 GRFs and joint kinematics, this discussion will solely focus on the differences between the  
260 combined experimental conditions and the control condition.

261

262 Sprint times were very likely quickest in the control condition where RF was likely highest. This  
263 provides new experimental support for previous descriptive (Kugler & Janshen, 2010; Rabita et al.,  
264 2015) and regression-based (Kawamori et al., 2013; Morin et al., 2011; Slawinski et al., 2016)  
265 evidence which has identified the importance of a more horizontally directed GRF vector in sprint  
266 acceleration performance. Our results demonstrate the importance of this technical ability in an  
267 acute, within-participant design, and suggest that striving to improve RF within individual team  
268 sports athletes through acute technical alterations may be a beneficial strategy for improving sprint  
269 acceleration performance. As there was no effect of condition on the peak or average resultant  
270 GRF, our results also provide further support for the relative lack of importance of the magnitude of  
271 the resultant GRF vector. The observed changes in RF occurred primarily due to an increased  
272 peak in the vertical component of the GRF, which led to an increase in vertical impulse given that  
273 stance duration did not differ between the conditions. During sprint acceleration it has been  
274 suggested that provided sufficient impulse is directed vertically to allow time for the legs to be  
275 repositioned during flight in preparation for the next ground contact, all of the remaining force

276 should be applied horizontally (Hunter et al., 2005). As the increases in vertical impulse in the  
277 current study occurred in the conditions in which performance levels were lower, it thus appears  
278 that these increases were not necessary and negatively affected performance.

279

280 The changes in RF and sprint performance between conditions were also accompanied by  
281 changes in angular kinematics at touchdown, and these provide evidence of kinematic features of  
282 technique which may be associated with RF. In the control condition, the ankle was likely or very  
283 likely in a more dorsiflexed position, the knee in a likely more flexed position, and the hip possibly  
284 or likely extending more rapidly, compared with the experimental conditions. The larger mean  
285 differences and effect sizes for the ankle angle compared with the knee suggest that participants  
286 may have prioritised greater movements at the ankle in an attempt to follow the instructions. This is  
287 consistent with the findings of a systematic review of experimental running studies which identified  
288 that ankle joint kinematics are altered to a greater extent than knee or hip kinematics in studies  
289 designed to achieve acute technical changes in foot strike (Napier, Cochrane, Taunton, & Hunt,  
290 2015). It is therefore possible that alterations to ankle joint kinematics may have been the intended  
291 response to the experimental conditions but a concurrent increase in knee flexion compensated for  
292 this, explaining the lack of observed change in touchdown distance. Although touchdown distance  
293 was earlier proposed as a mechanism that could be important for determining RF, the current  
294 findings suggest that touchdown distance *per se* may not be a determining factor in RF but that  
295 specific joint configurations within the stance leg may be important. Previous research which has  
296 proposed the importance of touchdown distance for RF has either not reported the stance leg joint  
297 kinematics (Kugler & Janshen, 2010; McNitt-Gray et al., 2015), or has theoretically manipulated  
298 specific joint kinematics to achieve changes in touchdown distance (Bezodis et al., 2015). It is  
299 possible that greater ankle dorsiflexion and/or knee flexion at touchdown may help to acutely  
300 increase RF either directly due to body configuration or indirectly due to effects on related factors  
301 such as muscle-tendon unit lengths. Whilst we cannot determine this from the current repeated-  
302 measures group comparison, these findings provide experimental evidence of specific joint angular  
303 kinematics that are worthy of further cross-sectional, experimental or theoretical investigation for  
304 understanding the determinants of RF. Hip extensor velocity has been suggested to be important

305 during maximum velocity sprinting (Mann & Sprague, 1983) and the possible or likely change in hip  
306 extension angular velocity observed in the current study suggests that it may also be important for  
307 early acceleration. This finding is also potentially interesting in the context of recent evidence  
308 regarding the potential importance of the torque producing capability of the hip extensors and  
309 hamstring activity just prior to touchdown for horizontal force generation in sprint acceleration  
310 (Morin et al., 2015). However, given the magnitude of the effects observed in this study and the  
311 lower likelihood of this difference at the hip joint compared with other observed differences, further  
312 evidence is required in support of this finding.

313

314 Whilst the majority of the effects observed in this study were small, this is unsurprising given the  
315 well-established movement pattern being studied and the nature of the intervention. These small  
316 effects on technique and performance are meaningful in applied practice in team sports where  
317 fractions of a second can make the difference to, for example, reaching an opponent or getting to a  
318 ball first. This study has therefore demonstrated clear scope for, and potential value in, further  
319 investigation of acute manipulations to touchdown technique. It is important to note that  
320 performance levels were very likely highest in the control condition where participants were simply  
321 instructed to “sprint as quickly as possible”. Our findings therefore confirmed previous evidence  
322 (Kawamori et al., 2013; Kugler & Janshen, 2010; Morin et al., 2011; Rabita et al., 2015) and  
323 extended it on a within-participant basis, but they did not specifically identify that performance  
324 could be acutely improved relative to current levels. This very likely decrease in performance in  
325 both experimental conditions compared with the control condition initially appears to conflict with  
326 findings reported in the motor learning literature where attentional focus has been manipulated  
327 (see Wulf, 2013). Although not elite, all of our participants had been involved in team sports since  
328 adolescence and their sprint acceleration movement patterns were therefore likely to be highly  
329 automated. The majority of research that has demonstrated superior performance for participants  
330 adopting an external focus of attention has typically studied novice and inexperienced performers  
331 who would be at earlier stages of learning (Newell, 1985; Peh et al., 2011), and in one of the few  
332 studies where truly expert performers have been studied, both an external and internal attentional  
333 focus were found to negatively affect automaticity of movement compared to a control condition

334 (Wulf, 2008). This may explain why both internal and external focus conditions acutely led to a very  
335 likely reduction in performance in comparison with the control condition in our study. We  
336 intentionally used instructions grounded in an established theory to investigate this issue because  
337 of the exploratory nature of this study and because attentional focus manipulations have been  
338 widely shown to be effective in altering technique and performance outcome in numerous motor  
339 skills (Wulf, 2013). Technical alterations in an applied coaching environment have been suggested  
340 to acutely increase horizontal impulse production and/or favourably affect touchdown distance  
341 (McNitt-Gray et al., 2015), but specific details were not provided, and manipulations to the starting  
342 posture of an athlete may also provide a means through which to attempt to manipulate RF  
343 (Slawinski et al., 2016). Future applied work to understand the effects of more commonly adopted  
344 coaching instructions which could facilitate acute enhancements in performance, and investigation  
345 of the kinematic features of technique which they affect, is clearly required. The use of data-rich  
346 environments in combination with experiential coaching knowledge offers exciting potential for the  
347 future exploration of the efficacy of such acute manipulations. We also used a group-based design  
348 which did not consider the individual anthropometric or strength characteristics of the athletes, and  
349 it is possible that these could influence the specific strategy which is optimal for achieving a higher  
350 ratio of forces for a given individual. Future studies could therefore attempt to consider the  
351 combined influence of individual structure and changes in technique on any observed changes in  
352 sprint acceleration performance.

353

354 In summary, this study acutely manipulated the ratio of forces produced by team sports athletes  
355 during acceleration using verbal instructions. Performance levels were highest in the condition  
356 where ratio of forces was highest which aligns with recent evidence and extends it on a within-  
357 participant basis. Differences in lower limb angular kinematics were also evident at touchdown  
358 between conditions, with greater ankle dorsiflexion, greater knee flexion and increased hip  
359 extension velocity evident when RF and performance were higher. Attempts to alter RF within  
360 individuals appears to be a worthwhile strategy for coaches and scientists to pursue, and these  
361 specific kinematic features of technique provide potential mechanisms worthy of further  
362 investigation in both acute manipulations and longer-term technical or physical interventions.

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477 Table 1. Mean  $\pm$  SD for all dependent variables from each condition and main condition effects  
 478 from the repeated measures ANOVA.

Variable	Units	Group mean $\pm$ SD			Main condition effect (p)
		C	I	E	
<b>Ratio of forces</b>	%	<b>25.2 <math>\pm</math> 2.5</b>	<b>23.5 <math>\pm</math> 3.1</b>	<b>23.9 <math>\pm</math> 2.2</b>	<b>0.02</b>
<b>10 m sprint time</b>	s	<b>1.936 <math>\pm</math> 0.095</b>	<b>1.992 <math>\pm</math> 0.120</b>	<b>1.992 <math>\pm</math> 0.112</b>	<b>&lt;0.01</b>
Step length	m	1.37 $\pm$ 0.10	1.42 $\pm$ 0.10	1.41 $\pm$ 0.10	0.06
Flight time	s	0.076 $\pm$ 0.013	0.084 $\pm$ 0.017	0.081 $\pm$ 0.016	0.12*
Touchdown distance	m	0.115 $\pm$ 0.040	0.124 $\pm$ 0.040	0.128 $\pm$ 0.047	0.22
Foot touchdown velocity	m/s	1.31 $\pm$ 0.61	1.09 $\pm$ 0.74	1.14 $\pm$ 0.67	0.36
<b>Ankle angle at touchdown</b>	°	<b>1.6 <math>\pm</math> 3.2</b>	<b>-1.6 <math>\pm</math> 4.4</b>	<b>-0.9 <math>\pm</math> 4.4</b>	<b>&lt;0.01</b>
<b>Knee angle at touchdown</b>	°	<b>45.4 <math>\pm</math> 5.4</b>	<b>43.3 <math>\pm</math> 6.9</b>	<b>43.8 <math>\pm</math> 6.0</b>	<b>0.02</b>
Hip angle at touchdown	°	40.9 $\pm$ 8.5	40.0 $\pm$ 11.5	41.2 $\pm$ 10.8	0.37
Ankle angular velocity at touchdown	°/s	50 $\pm$ 102	59 $\pm$ 101	87 $\pm$ 113	0.08
Knee angular velocity at touchdown	°/s	-99 $\pm$ 139	-62 $\pm$ 129	-36 $\pm$ 123	0.06
<b>Hip angular velocity at touchdown</b>	°/s	<b>-502 <math>\pm</math> 105</b>	<b>-453 <math>\pm</math> 107</b>	<b>-468 <math>\pm</math> 121</b>	<b>0.03</b>
Stance duration	s	0.150 $\pm$ 0.018	0.144 $\pm$ 0.025	0.148 $\pm$ 0.023	0.28
Peak resultant force	BW	2.46 $\pm$ 0.26	2.56 $\pm$ 0.23	2.54 $\pm$ 0.21	0.11
Average resultant force	BW	1.63 $\pm$ 0.11	1.68 $\pm$ 0.10	1.66 $\pm$ 0.12	0.12*
Peak propulsive force	BW	0.75 $\pm$ 0.08	0.75 $\pm$ 0.07	0.76 $\pm$ 0.07	0.97
Peak braking force	BW	-0.53 $\pm$ 0.23	-0.52 $\pm$ 0.25	-0.53 $\pm$ 0.28	0.92
Average horizontal force	BW	0.26 $\pm$ 0.05	0.25 $\pm$ 0.04	0.25 $\pm$ 0.04	0.20
<b>Peak vertical force</b>	<b>BW</b>	<b>2.43 <math>\pm</math> 0.26</b>	<b>2.60 <math>\pm</math> 0.30</b>	<b>2.52 <math>\pm</math> 0.22</b>	<b>&lt;0.01</b>
Average vertical force	BW	1.54 $\pm$ 0.10	1.59 $\pm$ 0.10	1.57 $\pm$ 0.12	0.11*
Braking impulse	m/s	-0.04 $\pm$ 0.02	-0.04 $\pm$ 0.02	-0.04 $\pm$ 0.02	0.99
Propulsive impulse	m/s	0.51 $\pm$ 0.06	0.49 $\pm$ 0.07	0.49 $\pm$ 0.05	0.36
Net propulsive impulse	m/s	0.46 $\pm$ 0.05	0.44 $\pm$ 0.07	0.45 $\pm$ 0.06	0.78
<b>Vertical impulse</b>	<b>m/s</b>	<b>0.79 <math>\pm</math> 0.09</b>	<b>0.87 <math>\pm</math> 0.12</b>	<b>0.85 <math>\pm</math> 0.11</b>	<b>0.04*</b>

479 Variables highlighted in bold are those where a statistically significant ( $p < 0.05$ ) main effect was observed.

480 C = control condition, I = internal focus condition, E = external focus condition

481 \* ANOVA calculated with Greenhouse-Geisser correction due to non-sphericity.

482 Joint angles are all presented relative to the neutral standing trial. Positive angles represent dorsiflexion/flexion.

483 Positive angular velocity values represent dorsiflexion/flexion.

484 Table 2. Mean change  $\pm$  97% confidence intervals between each pair of conditions for the  
 485 variables where a significant main effect of condition was observed.

Variable	I - C	E - C	E - I
Ratio of forces (%)	-1.7 $\pm$ 1.7	-1.3 $\pm$ 1.1	0.4 $\pm$ 1.9
10 m sprint time (s)	0.056 $\pm$ 0.036	0.056 $\pm$ 0.042	0.000 $\pm$ 0.037
Peak vertical force (BW)	0.17 $\pm$ 0.10	0.09 $\pm$ 0.08	-0.08 $\pm$ 0.09
Vertical impulse (m/s)	0.08 $\pm$ 0.07	0.06 $\pm$ 0.04	-0.02 $\pm$ 0.08
Ankle angle at touchdown (°)	-3.3 $\pm$ 2.1	-2.5 $\pm$ 2.2	0.8 $\pm$ 1.6
Knee angle at touchdown (°)	-2.1 $\pm$ 2.0	-1.6 $\pm$ 1.7	0.5 $\pm$ 1.4
Hip angular velocity at touchdown (°/s)	49 $\pm$ 39	33 $\pm$ 49	-15 $\pm$ 39

486 C = control condition, I = internal focus condition, E = external focus condition

487 Negative changes in angle represent a more plantar flexed ankle joint and a more extended knee joint.

488 Positive changes in angular velocity at the hip joint represent a less rapid extension velocity (i.e. a positive value is a tendency towards  
 489 greater flexion velocity).

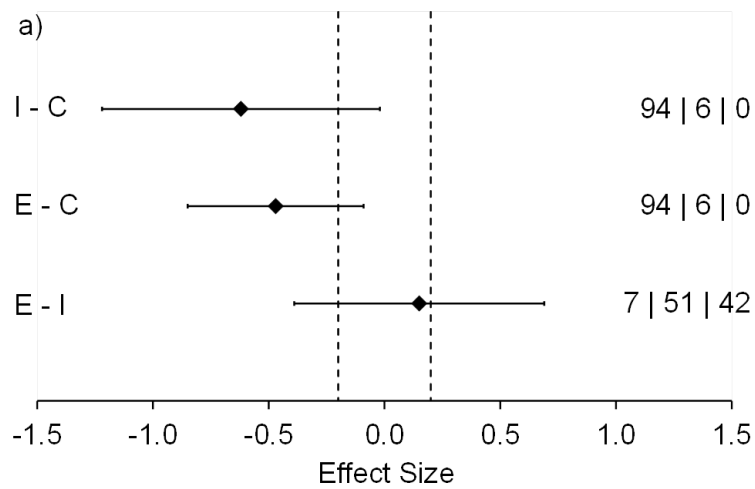
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491 *Figure legends*

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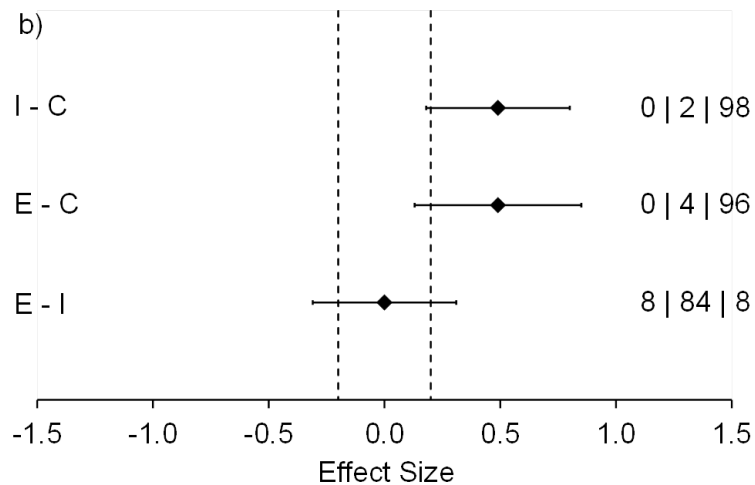
493 Figure 1. Effect sizes (with error bars representing 97% confidence intervals) between the control  
494 (C), internal focus (I) and external focus (E) conditions for a) ratio of forces, b) 10 m sprint time, c)  
495 peak vertical ground reaction force, d) vertical impulse, e) ankle angle at touchdown, f) knee angle  
496 at touchdown, and g) hip angular velocity at touchdown. Values on the right hand side of each  
497 figure provide the percentage likelihood that the effect is substantially negative | trivial | positive.

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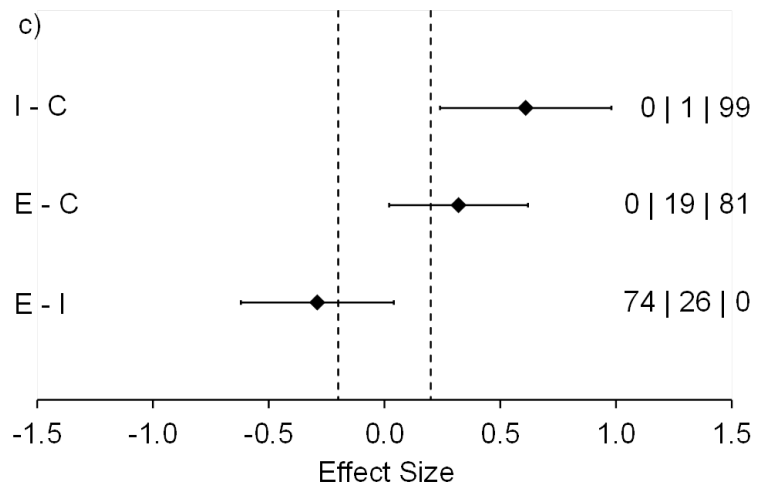
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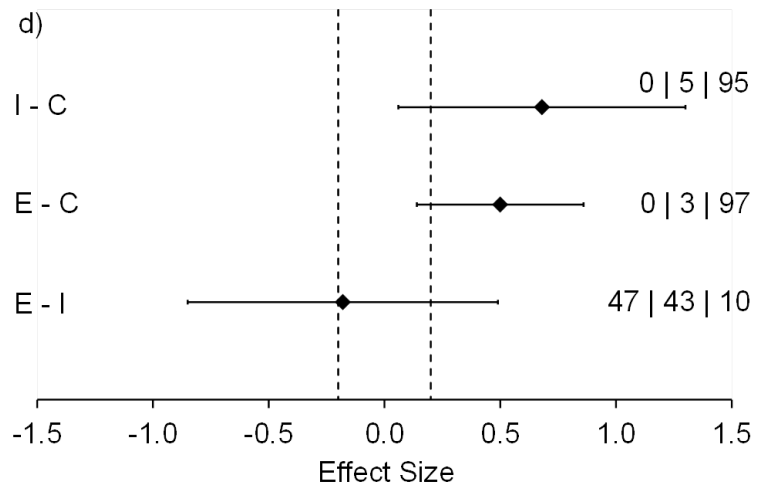
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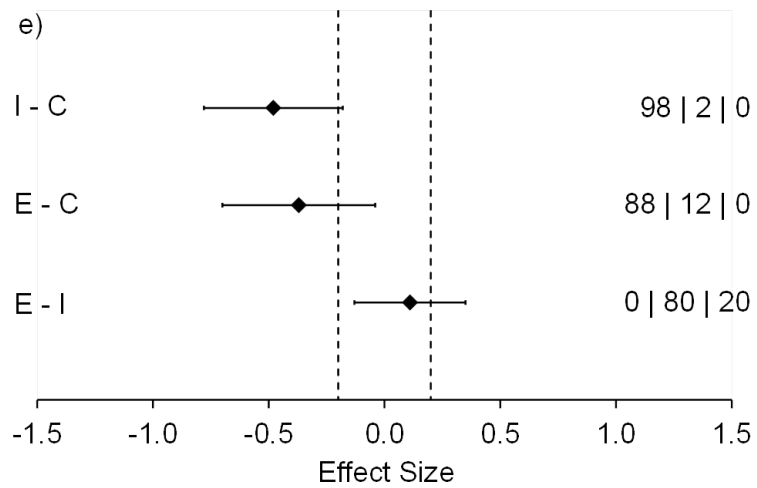
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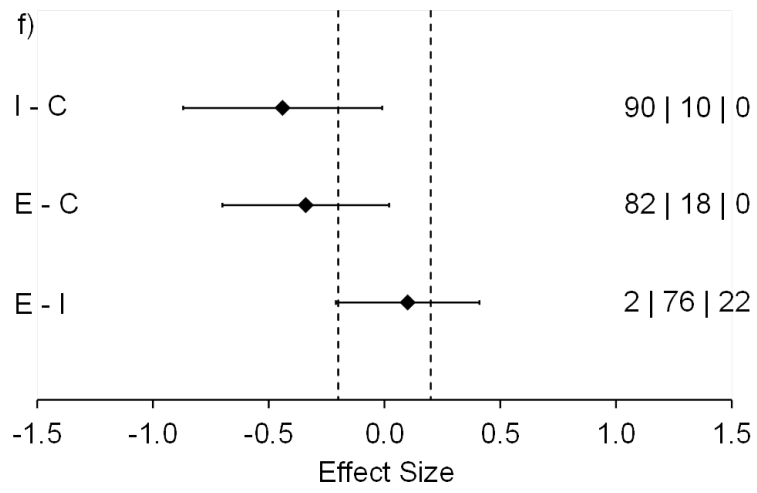
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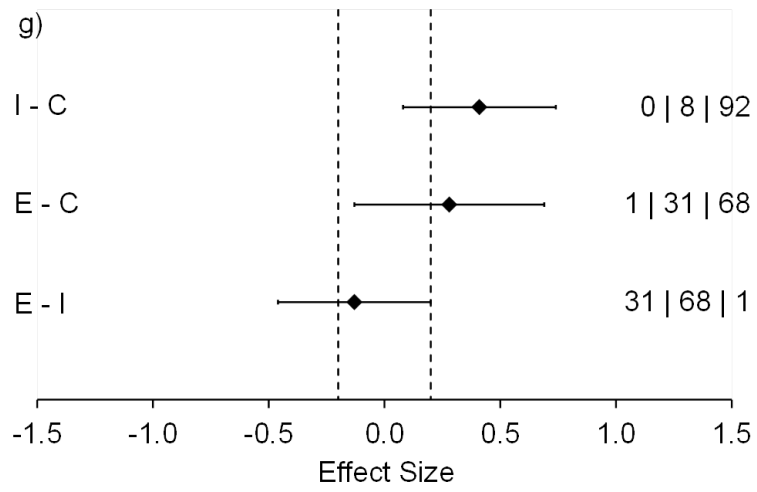
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