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

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Running title: GRF orientation and acceleration performance

Keywords: attentional focus, biomechanics, ratio of forces, sprinting, technique.

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Abstract:

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

Introduction

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

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

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

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

Methods

The study was approved by the University Research Ethics Committee and 18 male team sport (Gaelic football, rugby union, soccer) athletes (mean ± SD: age = 22 ± 4 years, mass = 78.2 ± 10.5 kg, height = 1.76 ± 0.10 m) provided written informed consent to participate. Participants completed three 10 m sprints from a standing start in each of three counterbalanced conditions. Given the widespread use of verbal technical instructions in sprint coaching, different verbal instructions were provided immediately prior to each sprint in an attempt to manipulate ratio of forces between the three conditions. These instructions were based on the well-established motor learning manipulation of attentional focus (see Wulf, 2013 for a review) where internally and externally focussed instructions are used to direct a performer's attention towards either their movements (internal focus) or the effect of these movements on the environment (external focus). Attentional focus research has consistently demonstrated that manipulating verbal instructions is an effective means through which to acutely alter technique and performance outcome (Wulf, 2013), including during maximal effort vertical and horizontal jumping (Porter, Ostrowski, Nolan, & Wu, 2010; Wulf & Dufek, 2009) where GRF production is a key determinant of performance, as it is for sprint acceleration.

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

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

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

Marker trajectories were low-pass filtered using a 4th order Butterworth digital filter at 20 Hz and segmental kinematics were reconstructed from the tracking markers using an evenly-weighted inverse kinematics procedure (Lu & O'Connor, 1999). For the ground contact on the force platform, touchdown and toe-off were identified from the raw vertical GRF data (10 N threshold) and flexion/extension angles (Cardan X-Y-Z, expressed relative to the static trial in neutral standing) and angular velocities (resolved in the proximal segment) were calculated and identified at touchdown. Where touchdown occurred between frames of kinematic data, linear interpolation was used to obtain a closer representation of the true touchdown value. The antero-posterior velocity of the stance foot CM at touchdown was extracted as foot touchdown velocity, and the antero-posterior distance between the stance foot CM and the pelvis CM at touchdown was calculated (hereafter termed touchdown distance; a positive value represents foot ahead of pelvis). Peak and average GRFs during stance were identified and divided by body weight, and impulses were determined using the trapezium rule and divided by body mass to yield changes in velocity. Ratio of forces was calculated using the previously described procedures of Morin et al. (2011). Toe-off from the stance phase prior to that on the force platform was determined when the vertical position of the 5th metatarsal-phalangeal marker first exceeded 0.1 m (Lees, Steward, Rahnama, & Barton, 2009), and flight time from this step was determined. Step length for this step was calculated from the antero-posterior coordinates of the 5th metatarsal-phalangeal markers at adjacent toe-off events.

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

Results

There was a significant main effect of experimental condition on RF and sprint acceleration performance (i.e. 10 m sprint time; Table 1). Ratio of forces was likely lower (i.e. a more vertically directed GRF vector) in both the internal and external focus conditions compared with the control condition (by 1.7 ± 1.7% and 1.3 ± 1.1%, respectively (mean ± 97% confidence interval)), whilst the difference between the internal and external focus conditions was unclear (Figure 1a, Table 2). The 10 m sprint times were very likely longer (i.e. a lower level of performance) in both the internal and external focus conditions compared with the control condition (by 0.056 ± 0.036 s and 0.056 ± 0.042 s, respectively), whilst the difference between the internal and external focus conditions was unclear (Figure 1b, Table 2). When looking in greater detail at the GRF data, there was no significant main effect of experimental condition on the peak or average resultant force or its horizontal component but there was a main effect on the peak vertical GRF magnitude (Table 1). Peak vertical GRF was very likely greater in the internal focus condition compared with the control condition (by 0.17 ± 0.10 BW), likely greater in the external focus condition compared with the control condition (by 0.09 ± 0.08 BW), and possibly smaller in the external focus condition compared with the internal focus condition (by 0.08 ± 0.09 BW; Figure 1c, Table 2). There was no significant main effect of experimental condition on any of the horizontal impulses (braking, propulsive or net propulsive) but there was a main effect of condition on vertical impulse (Table 1). Vertical impulse was very likely greater in both the internal and external focus conditions compared with the control condition (by 0.08 ± 0.07 m/s and 0.06 ± 0.04 m/s, respectively), whilst the difference between the internal and external focus conditions was unclear (Figure 1d, Table 2).

****Table 1 near here****

****Table 2 near here****

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

Regarding the kinematics at the instant of touchdown, there was a significant main effect on ankle angle, knee angle and hip angular velocity (Table 1). The ankle was very likely more plantar flexed at touchdown in the internal focus condition compared with the control condition (by 3.3 ± 2.1°), likely more plantar flexed at touchdown in the external focus condition compared with the control condition (by 2.5 ± 2.2°), whilst the difference between the internal and external focus conditions was likely trivial (Figure 1e, Table 2). The knee was likely more extended at touchdown in both the internal and external focus conditions compared with the control condition (by 2.1 ± 2.0° and 1.6 ± 1.7°, respectively), whilst the difference between the internal and external focus conditions was unclear (Figure 1f, Table 2). Hip extension angular velocity was likely slower in the internal focus condition compared with the control condition (by 49 ± 39°/s), possibly slower in the external focus condition compared with the control condition (by 33 ± 49°/s), and possibly faster in the external focus condition compared with the internal focus condition (by 15 ± 39°/s; Figure 1g, Table 2).

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

Discussion

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

Sprint times were very likely quickest in the control condition where RF was likely highest. This provides new experimental support for previous descriptive (Kugler & Janshen, 2010; Rabita et al., 2015) and regression-based (Kawamori et al., 2013; Morin et al., 2011; Slawinski et al., 2016) evidence which has identified the importance of a more horizontally directed GRF vector in sprint acceleration performance. Our results demonstrate the importance of this technical ability in an acute, within-participant design, and suggest that striving to improve RF within individual team sports athletes through acute technical alterations may be a beneficial strategy for improving sprint acceleration performance. As there was no effect of condition on the peak or average resultant GRF, our results also provide further support for the relative lack of importance of the magnitude of the resultant GRF vector. The observed changes in RF occurred primarily due to an increased peak in the vertical component of the GRF, which led to an increase in vertical impulse given that stance duration did not differ between the conditions. During sprint acceleration it has been suggested that provided sufficient impulse is directed vertically to allow time for the legs to be repositioned during flight in preparation for the next ground contact, all of the remaining force should be applied horizontally (Hunter et al., 2005). As the increases in vertical impulse in the current study occurred in the conditions in which performance levels were lower, it thus appears that these increases were not necessary and negatively affected performance.

The changes in RF and sprint performance between conditions were also accompanied by changes in angular kinematics at touchdown, and these provide evidence of kinematic features of technique which may be associated with RF. In the control condition, the ankle was likely or very likely in a more dorsiflexed position, the knee in a likely more flexed position, and the hip possibly or likely extending more rapidly, compared with the experimental conditions. The larger mean differences and effect sizes for the ankle angle compared with the knee suggest that participants may have prioritised greater movements at the ankle in an attempt to follow the instructions. This is consistent with the findings of a systematic review of experimental running studies which identified that ankle joint kinematics are altered to a greater extent than knee or hip kinematics in studies designed to achieve acute technical changes in foot strike (Napier, Cochrane, Taunton, & Hunt, 2015). It is therefore possible that alterations to ankle joint kinematics may have been the intended response to the experimental conditions but a concurrent increase in knee flexion compensated for this, explaining the lack of observed change in touchdown distance. Although touchdown distance was earlier proposed as a mechanism that could be important for determining RF, the current findings suggest that touchdown distance *per se* may not be a determining factor in RF but that specific joint configurations within the stance leg may be important. Previous research which has proposed the importance of touchdown distance for RF has either not reported the stance leg joint kinematics (Kugler & Janshen, 2010; McNitt-Gray et al., 2015), or has theoretically manipulated specific joint kinematics to achieve changes in touchdown distance (Bezodis et al., 2015). It is possible that greater ankle dorsiflexion and/or knee flexion at touchdown may help to acutely increase RF either directly due to body configuration or indirectly due to effects on related factors such as muscle-tendon unit lengths. Whilst we cannot determine this from the current repeated-measures group comparison, these findings provide experimental evidence of specific joint angular kinematics that are worthy of further cross-sectional, experimental or theoretical investigation for understanding the determinants of RF. Hip extensor velocity has been suggested to be important during maximum velocity sprinting (Mann & Sprague, 1983) and the possible or likely change in hip extension angular velocity observed in the current study suggests that it may also be important for early acceleration. This finding is also potentially interesting in the context of recent evidence regarding the potential importance of the torque producing capability of the hip extensors and hamstring activity just prior to touchdown for horizontal force generation in sprint acceleration (Morin et al., 2015). However, given the magnitude of the effects observed in this study and the lower likelihood of this difference at the hip joint compared with other observed differences, further evidence is required in support of this finding.

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

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

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

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Table 1. Mean ± SD for all dependent variables from each condition and main condition effects from the repeated measures ANOVA.

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

Variables highlighted in bold are those where a statistically significant ($p < 0.05$) main effect was observed.
C = control condition, I = internal focus condition, E = external focus condition
* ANOVA calculated with Greenhouse-Geisser correction due to non-sphericity.
Joint angles are all presented relative to the neutral standing trial. Positive angles represent dorsiflexion/flexion.
Positive angular velocity values represent dorsiflexion/flexion.

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

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

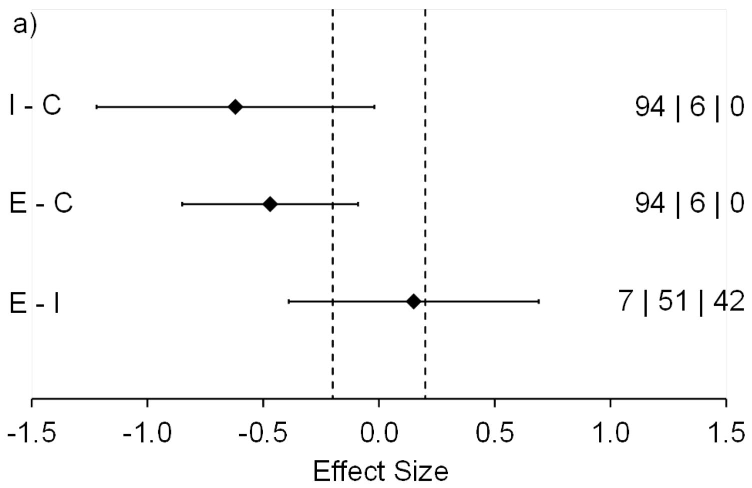
C = control condition, I = internal focus condition, E = external focus condition

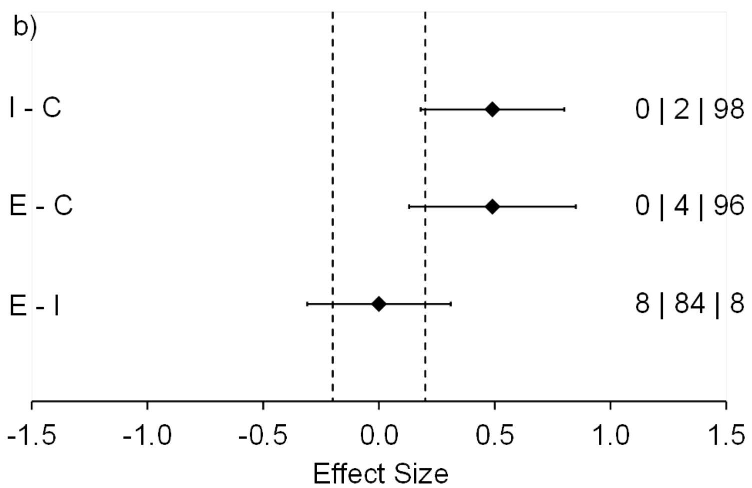
Negative changes in angle represent a more plantar flexed ankle joint and a more extended knee joint.

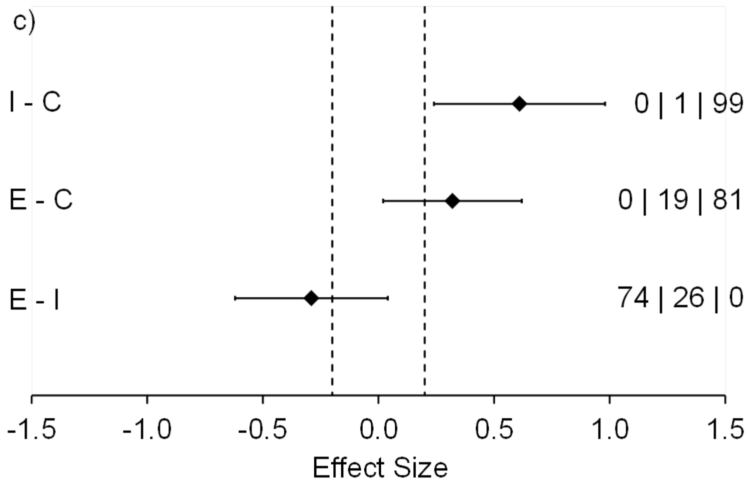
Positive changes in angular velocity at the hip joint represent a less rapid extension velocity (i.e. a positive value is a tendency towards greater flexion velocity).

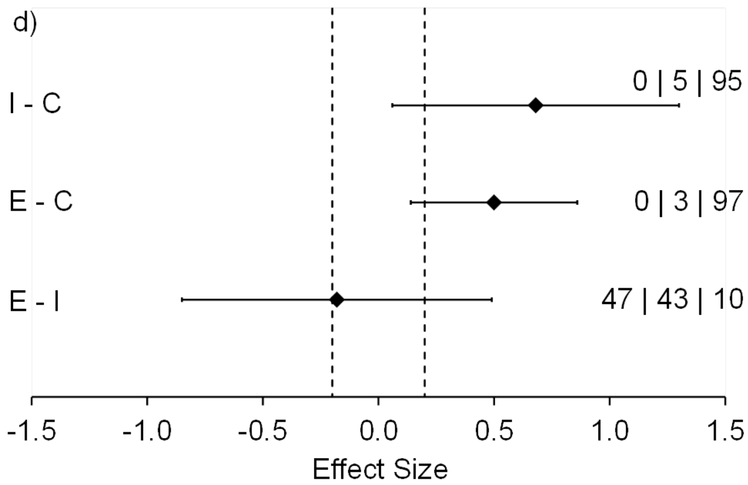
Figure legends

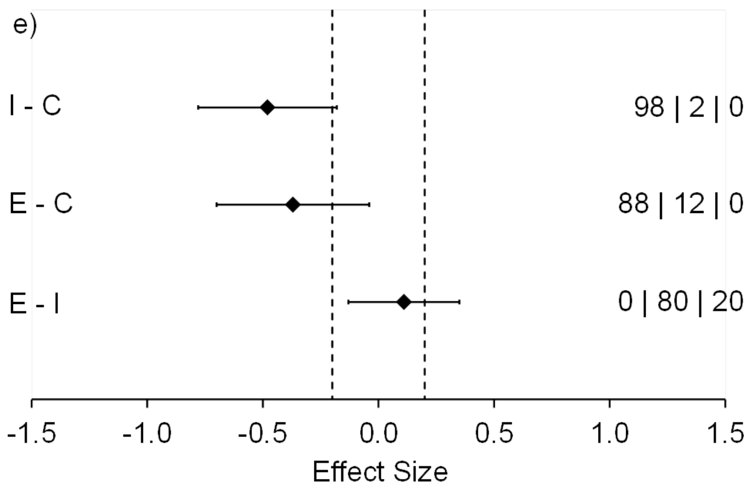
Figure 1. Effect sizes (with error bars representing 97% confidence intervals) between the control (C), internal focus (I) and external focus (E) conditions for a) ratio of forces, b) 10 m sprint time, c) peak vertical ground reaction force, d) vertical impulse, e) ankle angle at touchdown, f) knee angle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

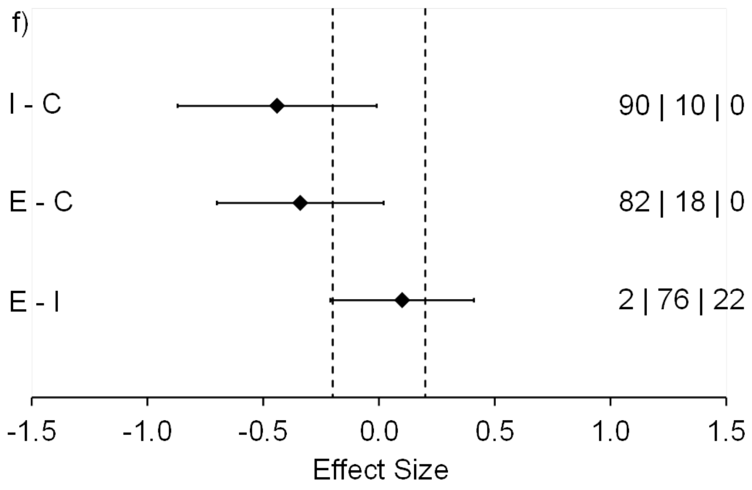


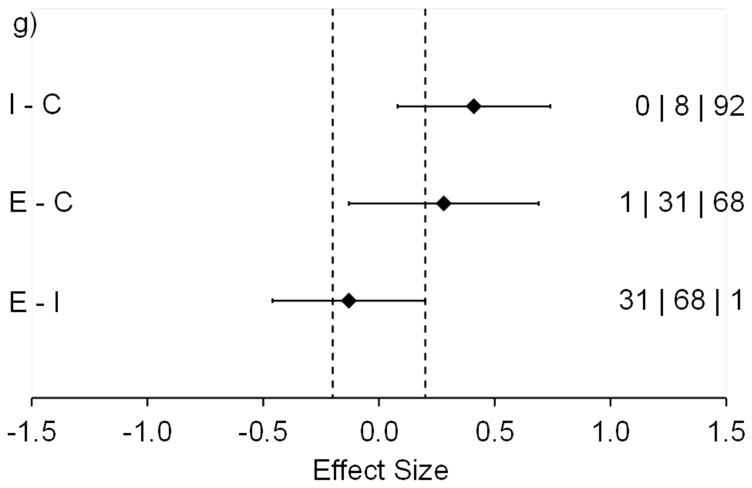



c)
I - C
0 | 1 | 99
E - C
0 | 19 | 81
E - I
74 | 26 | 0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Effect Size


d)
I - C
0 | 5 | 95
E - C
0 | 3 | 97
E - I
47 | 43 | 10
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Effect Size


e)
I - C
98 | 2 | 0
E - C
88 | 12 | 0
E - I
0 | 80 | 20
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Effect Size


f)
I - C
90 | 10 | 0
E - C
82 | 18 | 0
E - I
2 | 76 | 22
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Effect Size


g)
I - C
0 | 8 | 92
E - C
1 | 31 | 68
E - I
31 | 68 | 1
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Effect Size