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Ankle and knee kinetics between strike patterns at common training speeds in competitive male runners

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Abstract
The purpose of this study was to investigate the interaction of foot strike and common speeds on sagittal plane ankle and knee joint kinetics in competitive rear foot strike (RFS) runners when running with a RFS pattern and an imposed forefoot strike (FFS) pattern. Sixteen competitive habitual male RFS runners ran at two different speeds (i.e. 8 and 6 min mile^{-1}) using their habitual RFS and an imposed FFS pattern. A repeated measures analysis of variance was used to assess a potential interaction between strike pattern and speed for selected ground reaction force (GRF) variables and, sagittal plane ankle and knee kinematic and kinetic variables. No foot strike and speed interaction was observed for any of the kinetic variables. Habitual RFS yielded a greater loading rate of the vertical GRF, peak ankle dorsiflexor moment, peak knee extensor moment, peak knee eccentric extensor power, peak dorsiflexion and sagittal plane knee range of motion compared to imposed FFS. Imposed FFS yielded greater maximum vertical GRF, peak ankle plantarflexor moment, peak ankle eccentric plantarflexor power and sagittal plane ankle ROM compared to habitual RFS. Consistent with previous literature, imposed FFS in habitual RFS reduces eccentric knee extensor and ankle dorsiflexor involvement but produce greater eccentric ankle plantarflexor action compared to RFS. These acute differences between strike patterns were independent of running speeds equivalent to typical easy and hard training runs in competitive male runners. Current findings along with previous literature suggest differences in lower extremity kinetics between habitual RFS and imposed FFS running are consistent among a variety of runner populations.

Keywords: *Biomechanics, kinetics, injury and prevention*

Introduction

The effects of foot strike patterns on running mechanics have recently received much attention in the literature (Gruber, Umberger, Braun, & Hamill, 2013; Hamill, Gruber, & Derrick, 2014; Paquette, Zhang, & Baumgartner, 2013; Rooney & Derrick, 2013; Shih, Lin, & Shiang, 2013; Williams, Green, & Wurzinger, 2012). Of the three most common strike patterns (rear foot, mid foot and fore foot; (Cavanagh & Lafortune, 1980)), rear foot strike (RFS) seems to be the most utilized foot strike among recreational and competitive runners (de Almeida, Saragiotto, Yamato, & Lopes, 2014; Hasegawa, Yamauchi, & Kraemer, 2007; Kasmer, Liu, Roberts, & Valadao, 2013; Larson et al., 2011). Recently, due to popular debate over the most optimal strike pattern with respect to injury prevention, there has been a common interest on the effects of imposed changes in foot strike patterns on lower extremity joint biomechanics (Delgado et al., 2013; Hamill et al., 2014; Kulmala, Avela, Pasanen, & Parkkari, 2013; Rooney & Derrick, 2013; Shih et al., 2013; Stearne, Alderson, Green, Donnelly, & Rubenson, 2014; Williams et al., 2012). As injury rates have been reported to be higher in a sample of habitual RFS runners (e.g. hip, knee, lower back, tibia and plantar fascia) compared to habitual midfoot strike (MFS) or forefoot strike (FFS) runners (Daoud et al., 2012), supporters of FFS running, including barefoot running enthusiasts (McDougall, 2011), have proposed that RFS runners could benefit from adopting a non-RFS pattern (e.g. MFS and FFS). If runners choose to switch foot strike patterns, clinicians often advise these runners to do so gradually as an acute increase in stresses applied to previously unloaded tissue caused by changes in lower extremity mechanics may be injurious.

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Indeed, when habitual RFS runners acutely switch to a FFS pattern, the impact peak of the vertical ground reaction force (GRF) is generally absent (Lieberman et al., 2010), the average and peak loading rate (LR) of the impact peak (Diebal, Gregory, Alitz, & Gerber, 2012; Giandolini et al., 2013; Lieberman et al., 2010; Shih et al., 2013) and step length (Gruber et al., 2013) are reduced, while peak internal ankle plantarflexor moment (Kulmala et al., 2013; Rooney & Derrick, 2013; Stearne et al., 2014) and net eccentric plantarflexor power (Stearne et al., 2014; Williams et al., 2012) are increased. Further, an acute switch to FFS reduces peak internal knee extensor moment (Stearne et al., 2014) and net knee extensor eccentric power (Stearne et al., 2014; Williams et al., 2012) in habitual RFS runners. These findings suggest greater loads placed on the ankle joint and greater plantarflexor involvement when FFS is acutely imposed while greater loads to the knee joint and greater knee extensor involvement are observed in habitual RFS. Thus, current biomechanical comparisons of acute changes in strike patterns suggest that both techniques may be injurious with the risk of tissue damage between strike patterns at different sites or joints.

Although biomechanical changes observed when a FFS pattern is imposed in habitual RFS runners are well known, many factors still need to be addressed to expand current literature findings. For example, previous studies comparing joint kinetics between strike patterns have only used one running speed (e.g. predetermined or self-selected) (Giandolini et al., 2013; Hamill et al., 2014; Kulmala et al., 2013; Rooney & Derrick, 2013; Shih et al., 2013; Stearne et al., 2014; Williams et al., 2012), non-runners or unmentioned athlete type (Delgado et al., 2013; Giandolini et al., 2013; Shih et al., 2013) and, mixed running ability or experience (e.g. competitive/high mileage (Rooney & Derrick, 2013; Stearne et al., 2014) or medium or low/unmentioned weekly mileage (Delgado et al., 2013; Gruber et al., 2013; Hamill et al., 2014; Williams et al., 2012)). Peak sagittal ankle and knee joint moments increase with running speed (Arampatzis, Bruggemann, & Metzler, 1999) and peak ankle plantar flexor moment appears to increase to a greater extent than peak knee extension moment in RFS runners with increased running speed (de David, Carpes, & Stefanyshyn, 2015; Petersen, Nielsen, Rasmussen, & Sorensen, 2014). However, none of these previous studies compared joint kinetics between strike patterns as running speed increased. Since some habitual RFS runners tend to transition to a FFS when running speed increases from 2.2 to 6.1 m s^{-1} (Forrester & Townend, 2015), understanding potential interaction effects of habitual RFS and imposed FFS with common running speeds on lower extremity joint kinetics is of interest.

Therefore, the primary purpose of this study is to investigate the interaction of habitual RFS and imposed FFS and, two common running speeds on GRF variables and, sagittal plane ankle and knee joint kinetics in competitive RFS male runners. It was hypothesized that changes in ankle and knee kinetics between foot strike patterns may be different at a slower than a faster run speed. This hypothesis was based on what appears to be at least a small interaction of speed and foot strike pattern on metabolic cost when habitual RFS runners use an imposed FFS (Gruber et al., 2013). We also expected that the LR of the vertical GRF and peak knee joint kinetics would be greater in RFS compared to FFS while peak ankle kinetics would be greater in FFS compared to RFS. Ankle and knee joint kinematics were also analysed to provide mechanistic explanations for changes in kinetic variables.

Methods

Participants

Sixteen competitive male runners were recruited to participate in this study ($\bar{X} = 72.0$, $s = 11.0$ kg; $\bar{X} = 1.80$, $s = 0.07$ m; $\bar{X} = 22.0$ and $s = 2.2$ kg/m^2). Habitual male RFS runners who ran at least 32 km per week ($\bar{X} = 66.9$ and $s = 25.9$ km per week), who still participated in competitive races, and who were currently free from any lower extremity injuries volunteered for the study. Participants attended one laboratory testing session and written consent (approved by the Institutional Review Board for Human Participants Research) was obtained from all participants.

Experimental setup

A 9-camera motion analysis system (120 Hz, Qualisys AB, Gotenburg, Sweden) was used to obtain three-dimensional (3D) kinematic data. GRF data were collected using a 3D force platform imbedded in the laboratory floor at the midpoint of the 20 m runway (1200 Hz, AMTI, Watertown, MA, USA). Two photo-cells (63501 IR, Lafayette Instruments Inc., IN, USA) placed 3 m apart in the middle of the 20 m runway and an electronic timer (54035A, Lafayette Instruments Inc., IN, USA) were used to control running speed during each trial.

Protocol

Data were collected on the right leg of each subject, using spherical reflective markers placed on specific anatomical landmarks to define each segment. The pelvis was defined with the iliac crests and greater trochanters, and the hip joint centre (HJC) was calculated at the location of one-quarter the distance between the ipsilateral and contralateral greater trochanters (Weinhandl & O'Connor, 2010). The thigh was defined with the greater trochanter, the calculated HJC and the femoral epicondyles. The shank was defined with the femoral epicondyles and the malleoli. Finally, the foot was defined with the malleoli and the first and fifth metatarsal heads. Thermo-plastic shells with four reflective markers were placed on the pelvis, thigh and shank, and a plastic shell with three reflective markers was placed on the heel counter of the shoe to track each segment. This model was used since the anatomical landmarks used to define segments are palpable through manual palpation (van Sint Jan, 2007). To account for the axial offset of the foot segment during standing, a modified coordinate system for the foot was created. A virtual landmark located between metatarsal heads and the ankle joint location defined the anterior–posterior axis of the foot. The fifth metatarsal head marker was used to define the medio-lateral axis with respect to the ankle joint location. The vertical axis of the foot segment was orthogonal to the medio-lateral and anterior–posterior axes.

Before running trials, a static calibration trial was captured with both anatomical and tracking marker clusters on the body with only tracking markers left on the body during running trials. Participants performed five running trials using RFS and FFS at two goal speeds of $3.35\ \mathrm{m\ s^{-1}} \pm 5\%$ (i.e. 8 min mile^{-1}) and $4.47\ \mathrm{m\ s^{-1}} \pm 5\%$ (i.e. 6 min mile^{-1}) for a total of four conditions and 20 total trials. These running speeds were chosen with regard to previous literature (Rooney & Derrick, 2013; Stearne et al., 2014; Williams et al., 2012) and, to achieve running paces similar to 'recovery or easy' pace (i.e. 8 min mile^{-1}) and 'tempo or hard' pace (i.e. 6 min mile^{-1}) based on the runner population in this study. Participants had approximately 10 m to reach the desired speed before the first photocell and approximately 7 m to decelerate after crossing the second photocell. Two or three practice trials were provided before each condition to allow the participants to become familiar with the running speed. These trials were also provided to establish an appropriate start line to ensure right foot contact on the force platform in the middle of the runway without targeting. Participants wore their own shoes for all four conditions to maintain some external validity of the study design. For the RFS running trials, participants were simply instructed to run as they would during a normal run, whereas they were instructed to 'strike the ground with their forefoot' for the imposed FFS trials. Foot strike pattern was initially confirmed visually during over-ground running trials at the start of the testing session and was confirmed *post-hoc* using the strike index (SI) defined as the ratio of the centre of pressure (COP) location at foot strike relative to the length of the foot (Cavanagh & Lafortune, 1980). The length of the foot was defined as the distance between the heel marker and midpoint of the first and fifth metatarsal head marker. With this foot segment definition, a FFS can yield SI values greater than 100% of foot length. As previously observed (Paquette et al., 2013), the average SI for the FFS group in this study was greater than 100%. The running conditions (foot strike and speed) were randomized to prevent any order effects.

Data analyses

Visual3D software (C-Motion, Inc., MD, USA) was used to compute all variables of interest. A right-hand rule with a Cardan rotational sequence (x–y–z) was used for the 3D angular computations, where x represents the ML axis, y represents the AP axis and z represents the longitudinal axis. The ankle and knee joint angular kinematic and kinetic variables were expressed in the shank and thigh coordinate systems, respectively. Joint kinetic variables were computed using inverse dynamics as net internal moments and powers. Joint kinetic and GRF dependent variables included maximum vertical GRF, average LR of the vertical peak (LR; impact transient for RFS and maximal vertical GRF for FFS), early stance peak ankle dorsiflexor moment, peak ankle plantarflexor moment, peak eccentric ankle power, peak knee extensor moment and knee eccentric power. LR was measured as the slope of the vertical GRF curve within the time interval of 20% and 80% of the impact transient in RFS (Milner, Ferber, Pollard, Hamill, & Davis, 2006; Paquette et al., 2013) and of the maximal vertical GRF in FFS. Since a left heel marker was not used and we were therefore unable to measure step length, we computed step reach defined as the anterior–posterior distance between the right foot and pelvis centre of mass positions at initial ground contact as a spatio-temporal variable. Kinematic data were interpolated using a least-squares fit of a third-order polynomial with a three data point fitting and a maximum gap of 10 frames. Kinematic and GRF data were then filtered using a fourth-order Butterworth low-pass filter at 8 and 40 Hz, respectively. A threshold of 20 N of the vertical GRF was used to detect the start and end of the stance phase. The stance phase of each trial was interpolated from the start to end of stance to 100%. GRF were normalized to body weight (BW), and joint moments (N m) and powers (W kg^{-1}) were normalized to body mass. For all variables, the average of the five trials of each condition was used in the statistical analyses.

Statistical analyses

A two-way (Foot Strike × Speed) within-subject analysis of variance was used to evaluate all variable mean between foot strike patterns and speeds (22.0 SPSS, Chicago, IL, USA). Data normality was assessed using Levene's test of equality of error variances and all error variances were equal. Significance was set at an alpha level of 0.05. Cohen's d effect sizes (*ES*) were also reported to further assess mean differences with ≤0.70 representing a small effect, >0.70 and <1.2 representing a moderate effect, and ≥1.2 representing a large effect (Hopkins, 2013).

Results

Foot strike pattern was successfully controlled as the imposed FFS conditions showed a greater SI (slow: $\bar{X} = 107.3$, $s = 7.0\%$; fast: $\bar{X} = 108.4$ and $s = 7.9\%$) compared to RFS conditions (slow: $\bar{X} = 14.5$, $s = 4.4\%$; fast: $\bar{X} = 12.6$, $s = 6.7\%$; $ES = 14.77$; $P < .001$). Speed was also successfully controlled as the slow speed (RFS: $\bar{X} = 3.37$, $s = 0.06$ m s^{-1}; imposed FFS: $\bar{X} = 3.38$, $s = 0.05$ m s^{-1}) was measured to be slower than the faster speed (RFS: $\bar{X} = 4.54$, $s = 0.07$ m s^{-1}; imposed FFS: $\bar{X} = 4.55$, $s = 0.09$ m s^{-1}; $ES = 17.74$; $P < .001$).

No foot strike and speed interactions were observed for any kinetic variables. Primary kinetic variables showed foot strike main effects ($P < .05$; Table I). RFS yielded a greater vertical LR (88.1%, $ES = 2.09$), peak ankle dorsiflexor moment immediately after foot contact (415.8%, $ES = 4.45$), peak knee extensor moment (9.2%, $ES = 0.47$) and peak knee eccentric extensor power (59.9%, $ES = 1.82$). FFS yielded greater maximum vertical GRF (5.2%, $ES = 0.65$), peak ankle plantarflexor moment in mid-stance (16.5%, $ES = 1.56$) and peak ankle eccentric plantarflexor power (31.5%, $ES = 1.59$).

Primary kinetic variables also showed speed main effects ($P < .05$; Table I). Maximal vertical GRF (6.6%; $ES = 0.84$), vertical LR (20.5%; $ES = 0.56$), peak ankle plantarflexor moment (9.8%; $ES = 0.75$), peak ankle eccentric plantarflexor power (29.3%; $ES = 1.39$), peak knee extensor moment (6.1%; $ES = 0.33$) and peak eccentric knee power (13.1%; $ES = 0.42$) were greater at the fast compared to the slower speed.

Peak dorsiflexion in early stance showed a foot strike × speed interaction (Table II). *Post-hoc* Paired *t*-tests showed increased peak dorsiflexion with faster speed within both RFS (9.7%; $ES = 0.45$; $P < .001$) and imposed FFS strike (5.4%; $ES = 0.20$; $P = .023$) conditions and, reduced dorsiflexion with imposed FFS compared to RFS within both slow (9.9%; $ES = 0.39$; $P = .002$) and fast (14.3%; $ES = 0.60$; $P < .001$) speeds. Other secondary kinematic variables showed foot strike main effects ($P < .05$; Table II). Ankle range of motion (ROM) (38.8%, $ES = 2.38$) was greater in imposed FFS but step reach (12.7%, $ES = 1.43$) and knee ROM (21.0%, $ES = 1.28$) were greater in RFS.

Finally, secondary kinematic variables also showed speed main effects ($P < .05$; Table II). Step reach (12.2%; $ES = 0.97$), ankle ROM (4.7%; $ES = 0.15$) and peak knee flexion (4.2%; $ES = 0.32$) were all increased at the faster compared to the slower speed, while knee flexion ROM (6.8%; $ES = 0.38$) was reduced at the faster speed.

Discussion

The purpose of this study was to examine the effects of an acute transition from RFS to FFS running in habitual RFS runners on GRF as well as ankle and knee joint variables at two different speeds. Foot strike patterns were confirmed using the SI, with RFS patterns producing index values lower than 30% and imposed FFS pattern showing index values greater than 100% (Paquette et al., 2013). The results showed changes in sagittal ankle and knee joint kinetics that occur when an FFS is imposed on habitual RFS runners, regardless of running speed (i.e. slow or fast). These findings in competitive, high-mileage male runners are consistent with previous research conducted in different populations (e.g. mixed genders, low mileage, non-competitive, non-runners and single speed).

It was expected that a potential interaction of speed and foot strike existed for ankle and knee joint kinetics. This potential interaction was expected as metabolic cost during running is greater during imposed FFS compared to habitual RFS at slow (i.e. 3.0 m s^{-1} or ~8.9 min mile^{-1}) and medium (i.e. 3.5 m s^{-1} or ~7.7 min mile^{-1}) but this difference is absent at a faster speed (i.e. 4.0 m s^{-1} or ~6.7 min mile), which was still slower than the fast speed used in the current study (Gruber et al., 2013). At faster speeds, the similar metabolic cost appears to be the result of an increase in metabolic cost in RFS. However, the current results showed no interaction between habitual RFS and imposed FFS and running speed for GRF and joint kinetic variables.

As expected, a number of foot strike main effects were found for kinetic and kinematic variables. The

Table I. Sagittal plane ankle and knee kinetic and GRF variables for RFS and imposed FFS at both running speeds (mean ± SD) with *P*-values for main and interaction effects.

Variables	RFS		Imposed FFS		*P*-values		
	3.35 m s^{-1}	4.47 m s^{-1}	3.35 m s^{-1}	4.47 m s^{-1}	Foot strike	Speed	Interaction
Maximum vertical GRF (BW) $^{\#,*}$	2.61 ± 0.19	2.82 ± 0.19	2.78 ± 0.23	2.95 ± 0.27	< .001	< .001	.43
Vertical LR (BW s^{-1}) $^{\#,*}$	60.7 ± 16.5	75.1 ± 19.9	31.4 ± 7.03	40.8 ± 12.2	< .001	< .001	.24
Ankle DF moment (Nm kg^{-1}) $^{\#}$	0.29 ± 0.12	0.31 ± 0.13	−0.08 ± 0.02	−0.11 ± 0.03	< .001	.91	.24
Ankle PF moment (Nm kg^{-1}) $^{\#,*}$	−2.85 ± 0.33	−3.26 ± 0.31	−3.52 ± 0.37	−3.80 ± 0.45	<.001	<.001	.24
Ankle eccentric power (W kg^{-1}) $^{\#,*}$	−7.85 ± 1.22	−11.8 ± 1.75	−12.2 ± 2.18	−16.5 ± 2.81	<.001	<.001	.62
Knee extensor moment (Nm kg^{-1}) $^{\#,*}$	2.78 ± 0.51	2.90 ± 0.52	2.49 ± 0.51	2.71 ± 0.56	.001	.032	.30
Knee eccentric power (W kg^{-1}) $^{\#,*}$	−13.1 ± 2.61	−15.0 ± 3.53	−8.15 ± 2.08	−9.42 ± 3.17	<.001	.022	.44

Notes: [#]Significant foot strike main effect.
[*]Significant speed main effect.

current finding that the LR was greater in RFS running compared to imposed FFS is consistent with previous findings (Giandolini et al., 2013; Lieberman et al., 2010). Greater LRs have been linked to running related injuries, particularly tibial stress fractures (Milner et al., 2006; Zadpoor & Nikooyan, 2011). Although still no causal relationships have been established, the greater LR found observed in RFS may be related to the higher injury rates observed in habitual RFS runners (Daoud et al., 2012).

Despite the fact that LR was greater in RFS, maximal vertical GRF was greater in imposed FFS. The greater maximal vertical GRF in combination with the more anterior COP location (i.e. greater SI) appears to be responsible for the larger ankle plantarflexor moment found during imposed FFS compared to habitual RFS (Kulmala et al., 2013; Rooney & Derrick, 2013; Stearne et al., 2014). The greater dorsiflexion ROM with imposed FFS may provide more time to increase the dorsiflexion angular velocity in eccentric plantarflexors action. Along with the increased ankle plantarflexor moment, a faster dorsiflexion velocity would explain the greater peak negative ankle plantarflexor power (i.e. product of moment and angular velocity), which is consistent with previous findings of greater eccentric plantarflexor action during imposed FFS (Hamill et al., 2014; Stearne et al., 2014; Williams et al., 2012). Injury to the Achilles tendon (e.g. tendinopathy) represents up to 18% of the total injuries in runners (McCrory et al., 1999). Thus, greater plantarflexor involvement presents the possibility of increased stresses to the ankle plantarflexor complex over time. Liebl, Willwacher, Hamill, and Bruggemann (2014) reported greater plantarflexor strength in *habitual* FFS compared to *habitual* RFS. Thus, it seems plausible that during a RFS to FFS transition, if the increased stresses placed on the plantarflexors are gradual, a positive chronic adaptation for strengthening of the plantarflexor may serve as a protective mechanism to tissue damage (e.g. Achilles tendon).

Although the ankle plantarflexors appear to be more involved in FFS during stance, RFS produces

Table II. Sagittal plane ankle and knee kinematic variables for RFS and FFS at both running speeds (mean ± SD) with *P*-values for main and interaction effects.

Variables	RFS		Imposed FFS		*P*-values		
	3.35 m s^{-1}	4.47 m s^{-1}	3.35 m s^{-1}	4.47 m s^{-1}	Foot strike	Speed	Interaction
Peak ankle DF (°) $^{\#,*,\&}$	23.5 ± 5.32 ^{a,b}	25.8 ± 5.16^{b}	21.4 ± 5.92 ^{a}	22.5 ± 5.87	<.001	.001	.010
Ankle ROM (°) $^{\#,*}$	17.7 ± 3.86	19.0 ± 4.71	29.5 ± 5.29	30.5 ± 6.31	<.001	.029	.73
Peak knee flexion (°) *	−43.7 ± 6.14	−46.0 ± 6.14	−43.7 ± 6.61	−45.2 ± 6.54	.51	.005	.12
Knee ROM (°) $^{\#,*}$	−29.3 ± 3.09	−28.4 ± 5.03	−25.1 ± 3.40	−22.6 ± 4.08	<.001	.019	.21

Notes: [#]Significant foot strike main effect.
[*]Significant speed main effect.
[&]Significant foot strike × time interaction.
[a]Different than 4.47 m s^{-1} within foot strike.
[b]Different than imposed FFS within speed.
Step reach: AP difference between centre of mass (COM) of the foot and pelvis at foot contact; Peak ankle dorsiflexion (DF) in early stance; Ankle sagittal plane range of motion (ROM): from peak early stance plantarflexion (PF) to peak mid-stance DF in RFS and, from foot contact to peak DF in FFS; Peak knee flexion: flexion in mid-stance; Knee sagittal plane range of motion (ROM): from foot contact to peak flexion.

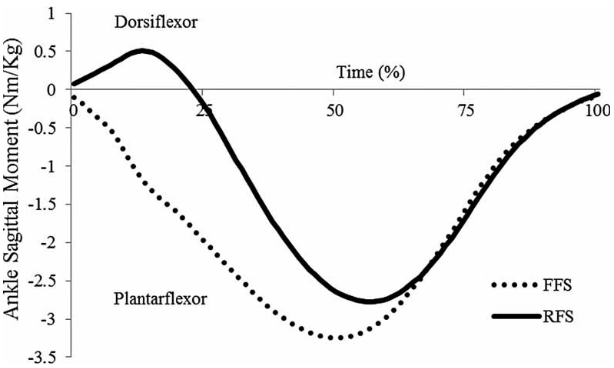

Figure 1. Stance phase normalized sagittal plane internal ankle moment curves for collapsed (i.e. all speeds) RFS and imposed FFS running trials of one participant representative of the sample population.

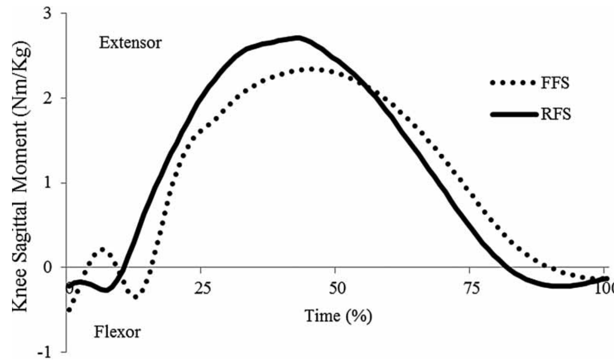

Figure 2. Stance phase normalized sagittal plane internal knee moment curves for collapsed (i.e. all speeds) RFS and imposed FFS running trials of one participant representative of the sample population.

a much greater dorsiflexor moment immediately following foot contact compared to imposed FFS (Table I; Figure 1). This early stance moment quantifies the net eccentric action of the dorsiflexors as the ankle plantarflexes to lower the foot to the ground immediately following heel strike (Perry, 1992). Many patients with chronic exertional compartment syndrome (CECS; lower leg pain) are distance runners (Detmer, Sharpe, Sufit, & Girdley, 1985; Shah, Miller, & Kuhn, 2004). The eccentric action of ankle dorsiflexors appears to be related to the onset of chronic anterior compartment syndrome (Tweed & Barnes, 2008) as greater intramuscular pressure of the tibialis anterior have been reported with excessive eccentric actions of the ankle (Friden, Sfakianos, & Hargens, 1986). Reduced eccentric dorsiflexor involvement during imposed FFS in runners seems to explain reductions in anterior compartment pressures in patients with CECS following a 6-week imposed FFS pattern intervention (Diebal et al., 2012). Peak dorsiflexion showed a foot strike and speed interaction. *Post-hoc* analyses showed that RFS generally produced greater ankle dorsiflexion compared to imposed FFS at both speeds but that the difference between strike patterns was not as large at the faster compared to the slow speed.

As expected, habitual RFS showed greater peak knee extensor moment (Figure 2) and negative power compared to imposed FFS similar to previously reported findings (Hamill et al., 2014; Stearne et al., 2014; Williams et al., 2012). In addition, a reduction in knee flexion ROM was also found in imposed FFS compared to habitual RFS (21.0%). The greater knee flexion ROM along with the unchanged peak knee flexion between strike patterns suggest a more extended knee at foot contact in RFS compared to imposed FFS. Although greater knee extensor involvement in RFS running may increase axial contact forces within the knee due to increased muscle force contribution, previous research did not find differences in estimated axial knee contact forces between habitual RFS and imposed FFS using musculoskeletal modelling (Rooney & Derrick, 2013). Kulmala et al. (2013) did however report lower estimated patellofemoral contact force in habitual RFS compared to habitual FFS during running as a result of a lower knee extensor moment. Thus, although an acute transition to FFS in habitual RFS runners may be harmful to the plantarflexors due to greater peak plantarflexor moment and force production (Rooney & Derrick, 2013), this transition may be acutely beneficial for habitual RFS to evade on-going knee symptoms while a treatment or intervention is completed.

Finally, all variables but peak dorsiflexor moment (nearly absent during FFS) showed a speed main effect. All kinetic variables and most kinematic variables increased with speed while knee flexion ROM was reduced at the faster speed. The increased magnitudes of kinetic variables with a faster speed were expected since GRFs increase with speed (De Wit, De Clercq, & Aerts, 2000) and it is well established that peak joint ankle and knee moments increase with faster running speeds (Arampatzis et al., 1999; de David et al., 2015; Petersen et al., 2014). Reduced knee flexion ROM with increased running speed has also been previously reported (Bishop, Fiolkowski, Conrad, Brunt, & Horodyski, 2006).

The current study focused on an acute strike pattern modification from habitual RFS to imposed FFS at two different common running speeds in competitive male runners in a non-fatigued state. It is possible that peripheral and/or central fatigue during longer training runs, or training cycles, could alter neuromuscular control of lower extremity joints. Such fatigue effects could alter their kinematic and kinetic behaviour in early stance between foot strike patterns and ultimately, altering potential internal stresses placed on the joints. Additionally, runners wore their running shoes during testing procedures, which could introduce variability in our results. However, the current within-subject design addresses this limitation as in this design, the participants serve as their own control and thus, variability between subjects is no longer a factor (Vincent & Weir, 2012). This study examined only competitive male runners who ran an average of 66.9 km per week (i.e. higher mileage). Our results may not be generalizable to female runners and to runners who are less trained.

Conclusions

This study provides further evidence that an imposed FFS appears to reduce eccentric knee extensor and ankle dorsiflexor involvement but produce greater eccentric ankle plantarflexor action compared to habitual RFS in competitive male runners. In addition, based on the lack of a speed and foot strike interaction, it appears that an acute transition to FFS from habitual RFS runners may be independent of slower (e.g. easy, long or recovery runs) and faster (e.g. tempo or interval runs) training speeds. Future studies should consider other runner population characteristics (i.e. weekly mileage, gender and experience) and, the interaction of fatigue with foot strike modifications on lower extremity joint kinetics in both healthy and injured runners.

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Disclosure statement

The authors have no financial interests or benefits from this work

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