Effects of running retraining on biomechanical factors associated with lower limb injury

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Abstract

Injury risk is an important concern for runners; however limited evidence exists regarding changes to injury risk following running style retraining. Biomechanical factors, such as absolute peak free moment, knee abduction impulse, peak foot eversion and foot eversion excursion, have been shown to predict lower limb injury. The aim of this study was to assess the effects of Pose running retraining on biomechanical factors associated with lower limb running injury. Twenty uninjured recreational runners were pair-matched based on their five km run time performance and randomly assigned to control (n = 10) and intervention (three 2-hour Pose running retraining sessions) groups (n = 10). Three dimensional kinetic and kinematic data were collected from all participants running at relative (REL: 1.5 $\text{km}\cdot\text{h}^{-1}$ below respiratory compensation point) and absolute (ABS: 4.5 $\text{m}\cdot\text{s}^{-1}$) speeds. Biomechanical factors associated with lower limb injury, as well as selected kinematic variables (to aid interpretation), were assessed. Following a six-week, non-coached time-period, all assessments were repeated. No changes to the biomechanical factors associated with lower limb injury examined in this study were observed ($P > 0.05$). Intervention group participants (presented as pre- and post-intervention respectively) exhibited an increased foot strike index (REL speed: 21.79 to 42.66%; $\text{ES}_\text{W} = 4.73$; $P = 0.012$ and ABS speed: 22.38 to 46.98%; $\text{ES}_\text{W} = 2.83$; $P = 0.008$), reduced take-off distance (REL speed: -0.35 to -0.32 m; $\text{ES}_\text{W} = 0.75$; $P = 0.012$), increased knee flexion at initial contact (REL speed: -14.11 to -18.50°; $\text{ES}_\text{W} = -0.88$ $P = 0.003$), increased ankle dorsiflexion at terminal stance (REL speed: -33.61 to -28.35°; $\text{ES}_\text{W} = 1.57$; $P = 0.036$) and reduced stance time (ABS speed: 0.21 to 0.19 s; $\text{ES}_\text{W} = -0.85$; $P = 0.018$). Finally, five km run time did not change (22:04 to 22:19 mins; $\text{ES}_\text{W} = 0.07$; $P = 0.229$). It was concluded that following Pose running retraining, retrained participants adopted a running style that was different to their normal style without changing specific, biomechanical factors associated with lower limb injury or compromising performance.

Keywords: Kinematics; kinetics; gait retraining; injury; pose.

Highlights

- Running style was retrained in a short time period using Pose running retraining.
- Retraining did not change biomechanical factors associated with lower limb injury.
- Retraining did not compromise five km time trial performance.

1. Introduction

Running is a popular form of recreational exercise in many parts of the world (Lun et al., 2004). The health benefits of regular exercise are apparent (Agresta & Brown, 2015). However, such health benefits are not devoid of risk; the incidence of lower limb running injuries – which can impede training – is reported to range from 19% to 79% (Van Gent et al., 2007). Advocates of the Pose method of running claim that the running style may reduce running injury and improve performance (Romanov & Robson, 2003). The Pose method of running asserts that an 'optimal running technique' exists, which emphasises a specific body geometry at foot strike (Dallam et al., 2005). This results in a ball-of-foot striking style, aligning the ipsilateral shoulder, hip and ankle of the stance limb (Arendse et al., 2004). When compared to heel-toe running, Pose method retrained runners exhibit shorter stance times, shorter stride lengths, greater knee flexion at initial contact, reduced centre of mass vertical oscillation as well as reduced eccentric work at the knee joint and increased eccentric work at the ankle joint (Arendse et al., 2004; Dallam et al., 2005; Fletcher et al., 2008). Previous studies (Arendse et al., 2004; Dallam et al., 2005; Diebal et al., 2012; Fletcher et al., 2008) have suggested that with appropriate training, running style can be successfully retrained in comparatively short time periods, i.e. five to seven training sessions. However, despite claims of reduced running injury (Romanov & Robson, 2003), Arendse et al. (2004) suggest that such alterations to running style could be associated with different types and frequencies of running injury. Whilst strong evidence for immediate biomechanical effects of running retraining exists (Barton et al., 2016), changes to injury susceptibility is an important concern when attempting to adopt a new running technique (Agresta & Brown, 2015). Currently, there is limited evidence regarding changes to injury susceptibility, following running style retraining using the Pose method.

Biomechanical assessment of running can provide insight into how loads experienced by the body can become abnormal, altering a runners' risk of injury (McClay & Manal, 1999). Exercise-related lower-leg pain (ERLLP) is a frequently reported form of overuse injury and is a broad term for many lower limb pathologies including shin splints, shin pain, medial tibial stress syndrome, periostitis, compartment syndrome and stress fractures (Willems et al., 2006). Willems et al. (2006) prospectively identified several mechanical characteristics during stance, such as central heel-strike, increased foot pronation (particularly greater eversion) and greater lateral roll off, as risk factors for ERLLP. Greater foot pronation in particular was associated with increased torsional loads about the tibia, due to shoe-surface friction (Willems et al., 2006). In running, the tibia is the most commonly injured bone (Barnes et al., 2008), with 35 – 49% of stress fractures attributed to tibial stress fracture (TSF). Milner and colleagues (2006) highlighted that values of peak adduction free moment, free moment (FM) at peak braking force and absolute peak free moment (|FM|) were greater in female runners with a history of TSF. Specifically, Milner et al. (2006) concluded that the magnitude of |FM| predicted TSF history in 66% of runners they studied. Milner et al. (2006) suggested that the greater incidence of TSF in females might reflect sex differences in lower limb geometry and stance phase alignment, a notion highlighted by broader analyses of running injury, i.e. ERLLP (Willems et al., 2006). The effects of skeletal alignment during stance were reiterated by Ferber et al. (2003), who demonstrated that increased Q-angles predisposed female runners to greater hip adduction and thus greater internal abduction moments at the knee. Skeletal alignment is of particular importance when considering the relative excursion of the knee to ground reaction forces in the frontal plane. Patellofemoral pain develops from the lateral aspect of the patella and is a common and chronic condition in running (Stefanyshyn et al., 2006). Stefanyshyn and colleagues (2006) highlighted greater internal knee abduction impulse as a contributing factor in the development of patellofemoral pain in runners. Specifically, larger internal knee abduction impulse was suggested to be degenerative and a function of skeletal alignment to frontal plane reaction forces (Stefanyshyn et al., 2006), i.e. moment arm magnitude.

Factors related to running injury are diverse and multifaceted (Agresta and Brown, 2015). However, a number of biomechanical factors (absolute peak free moment, knee abduction impulse, peak foot eversion and foot eversion excursion) have been identified as predictors of lower limb injury in retrospective and prospective running injury studies (Milner et al., 2006; Stefanyshyn et al., 2006; Willems et al., 2006). When attempting to adopt a new technique, changes to injury susceptibility is a concern. Therefore, given that injury susceptibility might change as a result of retraining running style, preliminary research into running style retraining on biomechanical factors, shown to predict lower limb running injury, is warranted. The aim of this study was to assess the effects of Pose running retraining on biomechanical factors associated with lower limb running injury.

2. Methods

2.1. Participants

Based on previous kinematic effects of Pose running retraining (Fletcher et al., 2008), a sample of nine participants (total of eighteen) was required to provide adequate statistical power for the study (alpha of 0.05 and power of 0.8). In response to local advertisements, twenty-nine uninjured recreational runners meeting inclusion criteria (aged between 18 – 45 years and injury-free at the time of participation) volunteered for the study. In total, twenty participants (twelve male, eight female) completed all assessments ($\bar{x} \pm s$: age = 29.4 ± 3.5 years; stature = 1.70 ± 0.10 m; mass = 69.3 ± 10.0 kg). Data from nine participants (five control group and four intervention group participants), who were unable to complete all assessments (due to seasonal illnesses and in one case, work commitments), were excluded from analyses. Prior to participation, all participants were briefed and written informed consent was obtained. Approval for all procedures was obtained from the Research Ethics Committee of the Faculty of Health and Wellbeing, Sheffield Hallam University.

2.2. Participant pair-matching and run speed determination

Prior to biomechanical assessment, all participants undertook an individual and maximal effort five km time trial ($\bar{x} \pm s$: time = 22:00 ± 3:13 mins; speed = 11.98 ± 1.37 $\text{km}\cdot\text{h}^{-1}$) on a 200 m indoor running track. Participants were pair-matched based on their five km run time performance and randomly assigned to control (n = 10, comprising four male and six female participants) or intervention (n = 10, comprising six male and four female participants) groups. On a subsequent day, a relative running speed (REL), reflecting each individual's functional capacity, was established. This was identified following a maximal effort, incremental speed (1 $\text{km}\cdot\text{h}^{-1}$ each minute) exercise test on a laboratory-based treadmill (Saturn, H-P-Cosmos Sports & Medical, GmbH, Germany) during which respiratory gases were measured (CPX Ultima, Medical Graphics Corporation, MN, USA). The REL run speed (1.5 $\text{km}\cdot\text{h}^{-1}$ below respiratory compensation point; Wasserman et al., 1987) is a metabolically sustainable speed associated with continuous running (Dekerle et al., 2003), e.g. ≥ 20 minutes, and reflects a relative workload speed to control for effort across participants. Following five km time trials, group assignment and REL run speed calculation, intervention and control group participants underwent biomechanical assessment to establish baseline measurements. Table 1 summarises anthropometric and descriptive data for intervention and control group participants.

Table 1. Anthropometric and descriptive data for control and intervention group participants.

	Age (years)	Stature (m)	Mass (kg)	Foot-strike (%)	Five km time (mins)	$\dot{V}O_{2Max}$ (mL·kg·min^{-1})	REL speed (m·s^{-1})
Intervention ($\bar{x}$ ± s)	29.5 ± 3.9	1.70 ± 0.16	69.4 ± 9.6	21.8 ± 4.4	22:04 ± 3:31	51.7 ± 7.8	3.4 ± 0.4
Control ($\bar{x}$ ± s)	29.3 ± 3.4	1.74 ± 0.09	69.2 ± 10.9	22.5 ± 6.3	21:55 ± 3:04	49.4 ± 8.9	3.3 ± 0.4

2.3. Laboratory-based biomechanical assessment

Fifty retro-reflective markers were affixed (adhesive tape) to anatomical landmarks and rigid segment clusters; twelve markers were subsequently removed for running trials due to marker redundancy and skin movement artifact. Three-dimensional position data of retro-reflective markers were recorded using an eight camera, digital motion capture system sampling at 200 Hz (Motion Analysis Corporation, Santa Rosa, CA, USA). Additionally, a force platform (9281CA, Kistler Instrumente, AG, Switzerland) measuring 0.6 × 0.4 m, mounted flush with the running surface and interfaced with the motion capture system, recorded three-dimensional ground reaction force data at 1000 Hz. Data for ten successful running trials (clean foot-force platform contact within ± 5% of desired running speed without obvious alterations to running stride) at both REL (Table 1) and fixed (ABS: 4.5 m·s^{-1}) running speeds were recorded. Running speed was monitored via two photocells placed 2 m apart (Brower Timing Systems, USA). Three-dimensional marker position and ground reaction force data were subsequently exported to Visual 3D (3.79, C-Motion, MD, USA); a full body biomechanical model was developed and applied. Prior to calculating ground reaction force variables, force platform channels were baseline adjusted (ten initial unloaded samples). A second order, lowpass Butterworth bidirectional filter was applied to all kinematic and kinetic data with cut-off frequencies of 10 and 50 Hz respectively. Calculated data were subsequently exported for further analysis in MATLAB (R2006b, The MathWorks, MA, USA).

2.4. Biomechanical analysis

Peak foot eversion and foot eversion excursion during stance were recorded. Stance phase knee abduction moment was recorded and knee abduction impulse calculated using the trapezoidal integration method. Free moment was calculated using Visual 3D and |FM| was recorded. All moment data were normalized by the product of body weight and stature to minimise the effects of sex related differences (Mosio et al., 2003). To characterise running style, sagittal plane kinematics, based on previous studies of this type (Arendse et al., 2004; Dallam et al., 2005; Fletcher et al., 2008; Lake et al., 1996) were assessed to aid interpretation. Ankle plantar-dorsiflexion angle, knee flexion-extension and hip flexion-extension angle were recorded at initial contact (IC) and terminal stance (TS). Further, peak knee flexion angle was recorded. Landing and take-off distance, defined as the horizontal component of the vector from the point of support to the centre of mass (COM) at initial contact and terminal stance respectively, was recorded. COM oscillation (vertical direction), stance time and foot strike index (described by Cavanagh and LaFortune, 1980) were also recorded.

2.5. Running retraining and non-coached time-period

Pose running retraining was delivered by certified instructors and consisted of three 2-hour retraining sessions (separate days) during a one-week period (refer to appendix for overview). Day one provided participants with a theoretical introduction and basic movement drills. The aim was to improve participant’s perception of basic movement through self-reflection and video feedback. Day two reinforced technical concepts of running retraining; specifically, the aim was to improve participant’s perception of ‘falling’ and ‘pulling’ in running through instructor led, group-based movement drills and feedback. Day three focussed on individual technique and skill development through specific, individual movement drills, supported with verbal and video feedback. Control group participants were instructed to maintain current training activities independently throughout the duration of the study. Following a six week, non-coached time-period, all participants repeated laboratory-based biomechanical assessments, using the same running shoes (participants' own) and running speeds. Further, all participants repeated the individual five km time trial on the same indoor, 200 m running track.

2.6. Statistical analysis

A two-way mixed ANOVA was performed for biomechanical parameters (identified in section 2.4) and five km run times using SPSS for Windows (16.0, SPSS Inc., Chicago, IL, USA) with an alpha level of 0.05. Homogeneity of variance and sphericity assumptions were assessed and satisfied using Levene's and Mauchly's tests respectively. In order to assess effect magnitudes, between-group (change score) and within-group effect sizes, given as: $ES_B = (\bar{x}_1 - \bar{x}_2) / S_C$ and $ES_W = (\bar{x}_{Post} - \bar{x}_{Pre}) / S_{Pre}$ respectively (Mullineaux et al., 2001), were also calculated. Effect sizes of 0.2, 0.5 and > 0.8 were considered small, moderate and large effects respectively (Mullineaux et al., 2001).

3. Results

Follow-up measurements for |FM|, knee abduction impulse, peak foot eversion angle and foot eversion excursion did not change ($P > 0.05$) for retrained participants running at REL or ABS run speeds (Table 2).

Table 2. Biomechanical factors associated with injury risk (REL and ABS speeds).

	Variable	Control ($\bar{x}$ ± s)		ES_W	Intervention ($\bar{x}$ ± s)		ES_W	ES_B	P
		Pre	Post		Pre	Post			
	|FM|	5.00 ± 1.72	5.20 ± 1.60	0.10	5.90 ± 2.17	6.60 ± 3.13	0.36	0.60	0.306
speed	Knee abduction impulse	-3.70 ± 2.60	-3.10 ± 2.58	0.28	-3.00 ± 2.13	-2.40 ± 1.65	0.25	-0.04	0.916
	Peak foot eversion (°)	5.94 ± 4.99	4.32 ± 4.47	-0.32	1.92 ± 6.41	2.71 ± 4.02	0.12	0.52	0.386

	Foot eversion excursion (°)	17.39 ± 3.94	16.66 ± 3.04	-0.18	17.09 ± 4.35	16.87 ± 3.80	-0.05	0.32	0.663
ABS speed	|FM|	7.02 ± 1.89	6.42 ± 2.03	-0.32	7.17 ± 3.41	7.90 ± 3.25	0.21	**0.82‡**	0.055
	Knee abduction impulse	-2.86 ± 1.98	-2.49 ± 2.22	0.19	-2.96 ± 2.26	-2.05 ± 1.47	0.41	0.37	0.369
	Peak foot eversion (°)	6.59 ± 5.24	4.16 ± 4.25	-0.47	1.28 ± 5.81	2.26 ± 5.14	0.17	0.62	0.234
	Foot eversion excursion (°)	18.50 ± 4.32	17.48 ± 3.93	-0.24	18.95 ± 4.26	17.76 ± 4.71	-0.28	-0.04	0.913

‡Large between-group effect size ($|ES_B| > 0.8$). |FM| and knee abduction impulse are normalised, dimensionless values and are × 10^{-3}.

Moderate and large between-group effects were observed for |FM| at REL (*P* = 0.306, ES_B = 0.60) and ABS (*P* = 0.055, ES_B = 0.82) speeds respectively. Further, moderate between-group effects were observed for peak foot eversion angle at both REL (*P* = 0.386, ES_B = 0.52) and ABS (*P* = 0.234, ES_B = 0.62) speeds. However, small within-group effects were observed for all of the aforementioned variables at both REL and ABS speeds (Table 2).

Table 3. Descriptive kinematics (REL and ABS speeds) and pair-matched, five km run times.

	Variable	Control ($\bar{x}$ ± s)		ES_W	Intervention ($\bar{x}$ ± s)		ES_W	ES_B	*P*
		Pre	Post		Pre	Post			
REL speed	Ankle angle: IC (°)	-2.25 ± 5.07	-2.23 ± 4.65	0.00	-1.91 ± 4.24	-8.50 ± 9.12	**-1.55†**	**-1.70‡**	**0.076**
	Ankle angle: TS (°)	-32.48 ± 6.10	-31.94 ± 5.15	0.09	-33.61 ± 3.34	-28.35 ± 6.52	**1.57†**	**1.15‡**	**0.036***
	Knee angle: IC (°)	-11.36 ± 2.64	-11.51 ± 2.60	-0.06	-14.11 ± 4.97	-18.50 ± 6.29	**-0.88†**	**-1.80‡**	**0.003***
	Knee angle: TS (°)	-20.40 ± 4.53	-22.28 ± 6.79	-0.41	-17.23 ± 4.11	-21.31 ± 5.18	**-0.99†**	-0.54	0.207
	Peak knee angle (°)	-44.64 ± 4.32	-45.88 ± 2.83	-0.29	-43.94 ± 5.16	-44.42 ± 3.66	-0.09	0.24	0.590
	Hip angle: IC (°)	37.39 ± 5.28	36.53 ± 7.16	-0.16	37.01 ± 9.91	37.18 ± 6.04	0.02	0.26	0.629
	Hip angle: TS (°)	-0.75 ± 3.64	-2.53 ± 6.44	-0.49	-4.18 ± 8.61	-1.53 ± 4.66	0.31	0.78	0.105
	Landing distance (m)	0.23 ± 0.03	0.24 ± 0.05	0.50	0.22 ± 0.04	0.24 ± 0.06	0.47	0.14	0.808
	Take-off distance (m)	-0.33 ± 0.03	-0.34 ± 0.04	-0.17	-0.35 ± 0.04	-0.32 ± 0.03	0.75	0.77	**0.014***
	Foot strike (%)	22.48 ± 6.31	21.42 ± 2.76	-0.17	21.79 ± 4.41	42.66 ± 21.99	**4.73†**	**3.43‡**	**0.012***
	COM oscillation (m)	0.10 ± 0.01	0.11 ± 0.01	0.32	0.10 ± 0.02	0.10 ± 0.01	-0.13	-0.66	0.395
	Stance time (s)	0.26 ± 0.03	0.25 ± 0.03	-0.38	0.25 ± 0.02	0.23 ± 0.02	-0.77	-0.19	0.643
ABS speed	Ankle angle: IC (°)	-3.17 ± 7.23	-4.79 ± 7.82	-0.22	-4.54 ± 5.68	-9.76 ± 7.75	**-0.92†**	-0.75	0.321
	Ankle angle: TS (°)	-32.43 ± 5.82	-32.30 ± 4.54	0.02	-33.10 ± 3.81	-28.01 ± 7.28	**1.33†**	**0.83‡**	0.116
	Knee angle: IC (°)	-13.21 ± 3.88	-13.34 ± 4.16	-0.03	-19.43 ± 5.63	-24.15 ± 4.73	**-0.84†**	**-1.17‡**	0.075
	Knee angle: TS (°)	-20.76 ± 5.26	-21.48 ± 5.01	-0.14	-19.45 ± 5.94	-24.73 ± 6.74	**-0.89†**	-0.79	0.080
	Peak knee angle (°)	-45.43 ± 4.21	-45.49 ± 2.83	-0.02	-46.15 ± 4.11	-44.37 ± 3.85	0.43	0.60	0.307
	Hip angle: IC (°)	41.93 ± 4.30	39.49 ± 6.31	-0.57	43.49 ± 7.80	41.23 ± 5.24	-0.29	0.04	0.939
	Hip angle: TS (°)	-3.89 ± 4.33	-4.50 ± 5.99	-0.14	-6.09 ± 7.03	-4.96 ± 4.62	0.16	0.42	0.405

Landing distance (m)	0.28 ± 0.03	0.26 ± 0.05	-0.36	0.25 ± 0.05	0.27 ± 0.05	0.35	0.76	0.116
Take-off distance (m)	-0.39 ± 0.03	-0.38 ± 0.04	0.30	-0.40 ± 0.03	-0.37 ± 0.03	**0.88†**	0.66	0.192
Foot strike (%)	23.42 ± 7.43	25.31 ± 8.10	0.26	22.38 ± 8.68	46.98 ± 23.77	**2.83†**	**3.58‡**	**0.008***
COM oscillation (m)	0.09 ± 0.01	0.09 ± 0.01	-0.31	0.09 ± 0.02	0.07 ± 0.01	**-0.81†**	**-1.05‡**	0.221
Stance time (s)	0.21 ± 0.01	0.21 ± 0.01	0.14	0.21 ± 0.02	0.19 ± 0.02	**-0.85†**	**-1.84‡**	**0.018***
Five km time (mins)	21:55 ± 3:04	21:43 ± 2:47	-0.06	22:04 ± 3:31	22:19 ± 3:13	0.07	0.46	0.229

*Significant interaction between groups ($P < 0.05$). ‡Large between-group effect size ($|ES_{B}| > 0.8$). †Large within-group effect size ($|ES_{W}| > 0.8$).

Retrained participants adopted a more ball-of-foot striking style ($P = 0.012$, $ES_{B} = 3.43$, $ES_{W} = 4.73$), increased knee flexion angle at initial contact ($P = 0.003$, $ES_{B} = -1.80$, $ES_{W} = -0.88$), increased ankle dorsiflexion at terminal stance ($P = 0.036$, $ES_{B} = 1.15$, $ES_{W} = 1.57$) and a reduced take-off distance ($P = 0.014$, $ES_{B} = 0.77$, $ES_{W} = 0.75$) at the REL run speed (Table 3). When considering within-group effects at the REL run speed (Table 3), retrained participants also exhibited trends of greater ankle plantarflexion at initial contact ($ES_{W} = -1.55$), greater knee flexion at terminal stance ($ES_{W} = -0.99$) and shortened (moderate effect) stance times ($ES_{W} = -0.77$). At the ABS run speed (Table 3), retrained participants exhibited a more ball-of-foot striking style ($P = 0.008$, $ES_{B} = 3.58$, $ES_{W} = 2.83$) and reduced stance times ($P = 0.018$, $ES_{B} = -1.84$, $ES_{W} = -0.85$). When considering within-group effects at the ABS run speed (Table 3), retrained participants also exhibited trends of greater ankle plantarflexion at initial contact ($ES_{W} = -0.92$), greater ankle dorsiflexion at terminal stance ($ES_{W} = 1.33$), greater knee flexion at initial contact and terminal stance ($ES_{W} = -0.84$ and -0.89 respectively), reduced take-off distance ($ES_{W} = 0.88$) and reduced oscillation of the COM ($ES_{W} = -0.81$). Finally, five km run time did not change for retrained participants ($P = 0.229$, $ES_{B} = 0.46$, $ES_{W} = 0.07$).

4. Discussion

To any runner, injury susceptibility is a principal concern when attempting to adopt a new technique (Agresta & Brown, 2015). Following three 2-hour running retraining sessions and a six week, non-coached time-period, retrained participants adopted a running style that differed significantly from their normal style, i.e. Figure 1. However, follow-up measurements of biomechanical factors associated with lower limb injury did not change (Table 2). Furthermore, no change to running performance, i.e. five km run time, was observed (Table 3).

Figure 1. Sagittal perspective of the three-dimensional kinetic model used for analysis. Sequential images are 0, 25, 50, 75 and 100% of stance for an intervention group participant pre (A) and post (B) intervention (ABS speed). Average COM horizontal velocity during stance was 4.32 and 4.31 m·s^{-1} whilst stance times were 0.245 and 0.195 s for pre and post-intervention respectively. The arrow from the force platform represents the resultant ground reaction force vector, illustrating heel-toe (A) and ball-of-foot striking styles (B).

4.1. Biomechanical factors associated with injury

As changes to the loading of biological structures might be associated with different types of running injury (Arendse et al., 2004); it is important to assess whether factors associated with lower limb injury risk change following running retraining. The current study assessed specific biomechanical factors previously identified to predict lower limb injury in running, i.e. absolute peak free moment (Milner et al., 2006), knee abduction impulse (Stefanyshyn et al., 2006), peak foot eversion and foot eversion excursion (Willems et al., 2006). Follow-up measurements of the aforementioned variables did not change ($P > 0.05$) for retrained participants running at either REL or ABS run speeds (Table 2).

Moderate and large (REL and ABS speeds respectively) positive between-group effects for absolute peak free moment, as well as moderate (REL and ABS speeds) positive between-group effects for peak foot eversion angle were observed. However, within-group effects for all of the aforementioned running injury predictor variables were small (Table 2). Findings indicate trends of different responses to absolute peak free moment and peak foot eversion angle, for control and intervention groups. For TSF injury, Milner et al. (2006) reported that, for every unit (1.0×10^{-3}) increment to absolute peak free moment, the likelihood of TSF history increased by a factor of 1.365. Similarly, Pohl et al. (2008) demonstrated that greater magnitudes of absolute free moment as well as foot eversion angle were associated with an elevated risk of TSF history, highlighting the multifaceted nature of TSF injury. Specifically, Pohl et al. (2008) reported that TSF likelihood increased by 1.37 per unit (1.0×10^{-3}) increment of absolute peak free moment. Further, TSF likelihood increased by 1.18 per unit (1°) increment of peak foot eversion (Pohl et al., 2008). This indicates that in combination, unit increments of absolute peak free moment and foot eversion angle increase TSF history likelihood by a factor of 1.62. For ERLLP, Willems et al. (2006) reported that greater magnitudes of peak foot eversion angle were associated with runners susceptible to ERLLP. A model, linking peak foot eversion angle increments to ERLLP likelihood, was not provided. However, results reported by Willems et al. (2006), indicate that injured (ERLLP) participants exhibited peak foot eversion and foot eversion excursion angles of 1.94° and 1.66° greater than uninjured participants respectively. For the current study, within-group effect sizes for all running injury predictor variables were small (Table 2). Further, changes to follow-up measurements for all running injury predictor variables within retrained participants were less than a one-unit increment or, in the case of foot eversion excursion, negative (-0.60° and -1.19° for REL and ABS run speeds respectively).

Causal relationships between abnormal running mechanics and subsequent running injury are well documented (Agresta & Brown, 2015). Whilst retraining running style may help to treat specific injuries (Barton et al., 2016), it is important that practitioners consider unforeseen changes to injury susceptibility as a result of retraining (Baggaley et al., 2017), owing to the multifaceted nature of running injury (Pohl et al., 2008). Current findings indicate that Pose running retraining did not elicit responses that might exacerbate risks of developing tibial stress fracture, patellofemoral pain or exercise related lower-leg pain. Future longitudinal prospective research is necessary to clarify these effects for different participant groups, e.g. injury status. For example, small changes observed within absolute peak free moment and peak foot eversion angle were inconsistent between control and intervention groups. This reflects the sensitivity of such measurements (Milner et al., 2006; Willems et al., 2006), particularly when inter-participant variability is considered over a six-week non-coached time-period. Therefore, future prospective running retraining research, where participants are grouped based on biomechanical parameters such as free moment, might aid the understanding and use of injury predictor variables for injury risk screening in running retraining.

4.2. Retrained running style

Changes to running style, following three 2-hour retraining sessions and a six week, non-coached time-period, were similar to desired and previously observed retraining effects. However, not all changes to running style reported by previous investigations were observed (Arendse et al., 2004; Dallam et al., 2005; Fletcher et al., 2008). Moreover, assessments at the faster ABS speed resulted in fewer changes to running style than at the REL speed (Table 3). The running style of retrained participants at the REL speed was characterised by a more ball-of-foot striking style, increased knee flexion at initial contact, increased ankle dorsiflexion at terminal stance and a reduced take-off distance (Table 3). Similarly, the running style of retrained participants at the ABS speed was characterised by a more ball-of-foot striking style, however reduced stance time was the only other effect observed at this speed (Table 3). The ABS speed (4.5 $m \cdot s^{-1}$ or 16.2 $km \cdot h^{-1}$) was included for a standardised comparison, however 4.5 $m \cdot s^{-1}$ was faster than the average five km run speed for all but three participants. It is therefore unlikely that the ABS speed was representative of 'regular' training speeds for this cohort of recreational runners. Given the influence of increased running speeds to running mechanics (Stergiou et al., 1999), grouped changes to running style at the ABS speed might have been masked by participants for whom the ABS speed was markedly faster than 'regular' training speeds.

Reduced take-off distances at the REL speed reflect previous investigations of running retraining using the Pose method (Arendse et al., 2004; Fletcher et al., 2008). However, the current study did not find comparable reductions in landing distance. This might reflect a different definition of landing and take-off distance. Fletcher et al. (2008) defined landing and take-off distance as the horizontal distance between the COM and fifth meta-tarsal. The current study defined this as the horizontal distance between the point of support and COM. Progression in retrained participants' foot strike index (Table 3), from rear-foot to ball-of-foot (approximately 20 – 24% of total foot length between REL and ABS conditions), might account for dissimilar reductions to landing distance. However, when foot placement at initial contact is considered with foot strike index progression, stance phase running volume (sagittal plane excursion of stance and swing feet relative to COM) was reduced, reflecting previous characterisations, i.e. shorter stride lengths (Arendse et al., 2004; Dallam et al., 2005; Fletcher et al., 2008).

At initial contact, a more ball-of-foot striking pattern was observed in retrained participants (REL and ABS speeds) through foot strike index progression and trends of greater ankle plantarflexion (Table 3). At terminal stance, retrained participants adopted a more neutral ankle angle for the REL speed; similar trends were also observed at the ABS speed. Such changes to ankle geometry at terminal stance reflect previous observations of a ‘foot lift’, reducing take-off distance (Arendse et al., 2004). The reduction of take-off distance for retrained participants was reflected by reduced stance times at the ABS speed; trends for shortened stance times were also observed at the REL speed. Retrained participants adopted a more flexed knee at initial contact at the REL speed with similar trends being observed at the ABS speed. Current findings reflect and expand upon those of Arendse et al. (2004). Peak knee flexion angle did not change following retraining, thereby not inducing extreme technique variations such as ‘Groucho’ running (McMahon et al., 1987). Although not directly measured, findings indicate a reduction to knee flexion excursion. Such findings might have implications for knee joint stiffness since increased joint stiffness is typically associated with reduced joint excursion (Butler et al., 2004). While such conditions might improve mechanical efficiency by better utilising tendo-muscular elasticity (Kyröläinen et al., 2001), relationships between joint stiffness and injury are not well established (Butler et al., 2004). Future research should consider such parameters given the altered skeletal loading and alignment profiles of retrained runners (Arendse et al., 2004).

Previous attempts to retrain running style have had varied success, reflecting the variety of training methods used (Barton et al., 2016). Recent studies have indicated that running retraining using the Pose method can be effective in comparatively short time periods (Arendse et al., 2004; Dallam et al., 2005; Diebal et al., 2012; Fletcher et al., 2008). However, although congruous changes toward the Pose running style were observed, current adaptations did not replicate previous reports (Arendse et al., 2004; Dallam et al., 2005; Diebal et al., 2012; Fletcher et al., 2008), reflecting difficulties associated with group-based running style retraining (Barton et al., 2016). Disparity in technique adoption highlights limitations within the current study. First, participants were an opportunistic sample of recreational runners and were therefore mixed in-terms of age, sex and running experience. Second, participant groups were pair-matched using five km run times and not running style; groups therefore contained a mixture of heel-toe and ball-of-foot runners. Finally, although participants were injury-free at the time of participation, previous injury history and other sports activities were not profiled. This is important as one intervention group participant who withdrew from the study due to work commitments, reported transient knee pain. The cause of transient knee pain however, could not be attributed to any individual activity the participant was engaged in, i.e. running retraining, soccer or triathlon. Future research assessing effects of running retraining on injury risk should therefore consider running style, injury history, other sporting activities and biomechanical injury predictors, e.g. free moment, when defining participant groups. For practitioners engaged in running style retraining, whether to treat specific injuries or improve performance, current work addresses a lack of knowledge regarding changes to injury risk as a result of Pose running retraining. Whilst current findings indicate that risks of developing tibial stress fracture, patellofemoral pain or exercise-related lower-leg pain did not change following Pose running retraining, the nature of running injury is multifaceted and many modes of running retraining exist. Therefore, it is important that when administering running retraining interventions, practitioners assess relevant factors associated with injury, to assess potential change to injury risk.

5. Conclusion

Following six hours of running retraining and a non-coached time-period of six weeks, retrained participants adopted a running style that differed significantly from their normal style. Based on evidence from retrospective and prospective running injury studies, running style retraining did not elicit responses that might contribute to a risk of developing tibial stress fracture, patellofemoral pain or exercise-related lower-leg pain. In conclusion, the findings of this study indicate that it is possible to retrain running style without changing lower limb injury risk or compromising five km time trial performance.

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Appendix: Pose method of running retraining intervention drills.

Summary of the week

Day 1: Developing the concept
Day 2: Reinforcing the concept
Day 3: Individual technique and skill development

Overall aims and objectives

Develop cognitive model of Pose, perception of falling and pulling the foot from the ground and finally auto-correction of technique.

Practical daily outline

Introduce the concept theoretically and practically. Utilise specific drills to gain a feel of the concept of falling and pulling the foot from the ground. Video each participant to aid learning. Give verbal and written feedback after each session.

Day 1

<u>Short theoretical session in a classroom</u>

There are four forces involved in running: gravity, ground reaction force, muscle force and muscle elasticity. Gravity, ground reaction force and muscle elasticity are free in reference to internal energy costs. Pose questions on how does gravity work in running and which external force moves the body forwards?
Show body tipping and falling forwards and assess muscle forces involved. Clarify gravity causes the tipping and no muscle forces were needed to fall. Explain then how to continue moving forwards by pulling the foot from the ground. Explain the use of muscle elasticity and its role in aiding pulling the foot from the ground. Emphasise the timing of falling and pulling the foot from the ground through the key concept of Pose (shoulder, hip and ankle vertical alignment).

<u>Key to learning</u>

Increase participant's perception of the movement. Ascertain how they felt after each drill and running activity.
1) Use Pose biomechanical model as standard to compare against.
2) Develop their perception but note their perceptions may be wrong so increase the correct perception.
3) They have to perceive two things: to feel falling and to pull the foot from the ground immediately they begin to fall forwards.

<u>Drills</u>

Warm-up: Video each participant running prior to intervention.

Falling position:

- Stand on heels and try and fall forwards. Try the same thing with the leg behind and in front. Interaction with support:
- Stop participants in a freeze frame. Ask them where their weight is on their feet.
- Lift heels to see if weight is on the ball of the foot.
- Unlock knees and rapidly lift heels
- Keep weight on the ball of the foot at all times.

Move the body as an integrated system:

- Push participant back and forth and side-to-side while maintaining an integrated body position.

Weight position in relation to foot and centre of mass:

- Place a hand on their chest and take the participant’s weight as they fall forwards.

Feel weight move from foot to chest:

- Repeat but let go this time.
- Repeat but demonstrate how small a lean is needed to fall forwards.
- Repeat and show where participant’s foot lands in front of their body.
- Repeat, but ask them to pull their foot as they fall.

Feel pull of the foot from the ground:

- Hold participant’s heel as they pull the foot from the ground
- Push foot down as they resist.

Perception drills for falling:

- Hand on belly button and feel vertical relationship to the ball of the foot.
- Repeat and fall forwards.
- Repeat and feel how small and angle is needed to fall.
- Run with fingers on belly button.
- Repeat with eyes closed; use partner.
- Arms stretched out behind the back and run.
- Hands pushing on hips and run.
- Hand on chest with partners and run.
- Partners fingers on back and run.

Range of motion of the lower-limb:

Emphasise a decreased range of motion. Show using running shoes the position of the foot, on landing and flight and impact again. Do not drive the leg forwards.

- Run and video for feedback

Rubber bands to illustrate a correct leg action:

- Leg behind and in front as they run with the bands attached to their ankles.
- Run with partners in front and behind with hands on their shoulders.
- Reduce effort needed by only using hamstrings to pull the foot.
- Reduce effort needed by only using the minimal amount of hamstrings to pull the foot.

Technique problems to look for:

- Landing ahead of the centre of mass with the foot; do not drive with hip flexors.
- Landing on toes; feel ball of the foot on landing.

- Landing rigidly; relax and land with a neutral ankle.
- Landing on the sides of the foot; use pull up toes drill.
- Landing on the sides of the foot and rigidly; use Pony, tapping, slow light running.
- Landing hard, decelerate foot with hamstrings.

Hips and muscle integration:

- Standard hip drill, front back, behind and sides and run after each one.
- Standing and push person from all sides while holding them. Ensure body remains integrated.
- Run and video for feedback.

Body integration drills (check perception):

- Partner running with eyes closed. Feel lightness and integration.
- Push from behind and resist with whole body and then run.
- Press back on partners hands hard and then run.
- Run while partner pressing down on their head to feel no vertical movement.

Summary

Reinforce participant’s perceptions. Can participant’s feel falling and pulling of the foot from the ground? Do participant’s feel lightness and body integration? Understand the model of gravity’s work on the body, body leads leg and the foot is pulled from the ground as participant’s fall forwards.

Day 2

Reinforcing the concept

Increase participant’s perception for falling and speed of pulling the foot from the ground.

- Run with arms in front and behind.
- Partners push the shoulder from the side intermittently to check rapid change of support while running.

Pulling:

- Use rubber bands to increase feel of hamstring work.
- Standing band work and running with bands
- Short sharp downhill run to feel pulling action
- Individual holds bands and pulls vertically upwards from the shoulders and push out to the side for increased tension. Pull foot vertically upwards.

Pattern of movement reinforcement:

- Pony drill
- Tapping drill
- Skipping drill
- Front lunge drill
- Run 200 m and video for feedback

Reinforce fall and pull:

- Press-up position without bands face down and upwards. Pull for hamstring work.
- Press-up position with bands face down and upwards. Pull for hamstring work. Run 400 m and video for feedback:
- Use a metronome or count to develop stride frequency of over 180 per minute.

Observe mistakes:

- Keep knees flexed; do not extend leg at toe-off
- Maintain a vertical alignment on landing.
- Do not land ahead of the centre of mass.
- Do not leave the support leg behind.
- Fall.
- Do not fix the ankle on landing.
- Hips not integrated.

Look for:

- Lightness.
- Body integration.
- Pose position on landing
- Ease of running
- No pressure, tightness or pain.
- Fall and pull action.

Summary

Can participant’s feel falling as they run? Can participant’s pull the foot from the ground as they run? Give specific drills for each individual from feedback.

Day 3

Individual technique development

- Pony, tapping and skipping.
- Cross steps.

Drills

- Jumps
- Run and video for feedback.
- Run on gravel to emphasise pulling of the foot.

Partner work with hips and hamstring and run:

- Jumps on one leg; movement in the hips not knee.
- Feel hip, knee, ankle and ball of foot light and loose.
- Harder hip work with partners

Summary

Give individual drills and comments.

Video running and give feedback.