Supplementary file 6 Biomechanical effects of altering strike pattern

FINDINGS	LEVEL OF EVIDENCE
EFFECT OF CUES TO TRANSITION FROM NATURAL RFS TO FFS WHILST SHOD	
Spatio-temporal	
↑ distance from foot strike point to centre of mass	Very limited (1 MQS[1])
Conflicting findings related to centre of mass vertical displacement	1 MQS[2] = ↓; 1 MQS[1] = no change
No difference in step rate or step length	Limited (2 MQS[1 3])
Ground reaction forces	
↑ peak vertical GRF	Moderate (3 MQS[2-4])
↑ peak anterior-posterior GRF and ALR	Very limited (1 MQS[2])
↓ Total power absorption	Limited (2 MQS[5 6])
Conflicting findings related to VALR	1 MQS[1] = ↓; 1 MQS[2] = no change
↓ VILR	Very limited (1 MQS[1])
↓ contact time	Very limited (1 MQS[1])
Conflicting findings related to total lower limb stiffness	1 MQS[2] = ↑; 1 MQS[1] = no change
Foot and ankle	
↓ ankle stiffness	Very limited (1 MQS[2])
↑ ankle power absorption	Limited (2 MQS[5 6])
↑ ankle power production	Very limited (1 MQS[6])
↑ internal ankle dorsiflexion moment during stance	Limited (1 LQS[7] and 1 MQS[6])
↑ peak internal ankle internal rotation moment	Very limited (1 MQS[6])
↑ ankle contact forces	Very limited (1 LQS[7])
↓ ankle dorsiflexion at foot strike	Moderate (4 MQS[1 2 5 8])
↓ ankle dorsiflexion at midstance and toe off	Very limited (MQS[8])
Conflicting findings related to ankle inversion/eversion kinematics	1 MQS[2] = ↑ ankle inversion at foot strike; 1 MQS[8] = no change
↑ ankle eversion ROM	Very limited (1 MQS[2])
↑ ankle dorsiflexion ROM	Limited (2 MQS[2 4])
Lower leg/tibia	
↑ damping coefficient (i.e. reduced ability to attenuate impact)	Very limited (1 MQS[9])

↑ peak tibial acceleration	Very limited (1 MQS[2])
↑ gastrocnemius and soleus muscle forces	Limited (1 MQS[3] and 1 LQS[7])
↑ pre-activation of gastrocnemius	Very limited (1 MQS[1])
↑ stance phase activation of gastrocnemius	Very limited (1 MQS[1])
↑ peroneal muscle forces	Very limited (1 LQS[7])
↓ TA muscle forces	Very limited (1 LQS[7])
↓ pre-activation of tibialis anterior	Very limited (1 MQS[1])
↓ stance phase activation of tibialis anterior	Very limited (1 MQS[1])
<u>Knee</u>	
↑ knee stiffness	Very limited (1 MQS[2])
↓ knee power absorption	Limited (2 MQS[5 6])
Conflicting findings related to peak internal knee extensor moment	1 LQS[7] = ↑; 1 MQS[4] = ↓
Conflicting findings related to knee flexion at foot strike	2 MQS[1 3] = ↑; 2 MQS[5 8] = no change
↓ knee flexion ROM	Moderate 3 MQS[2-4]
↓ peak and accumulative PFJ reaction force and PFJ stress	Limited (1 HQS[10] and 1 MQS[3])
↓ quadriceps and hamstring muscle force	Limited (1 MQS[3])
<u>Thigh</u>	
↑ pre-activation of rectus femoris	Very limited (1 MQS[1])
<u>Hip</u>	
Conflicting findings related to hip power absorption	1 MQS[5] = ↓; 1 MQS[6] = no change
Conflicting findings related to hip flexion at foot strike	1 MQS[1] = ↓; 1 MQS[5] = no change
Conflicting findings related to hip flexion/extension	3 MQS[1 4] = ↓ ROM; 1 MQS[8] = no change
EFFECT OF CUES TO TRANSITION FROM NATURAL FFS to RFS WHILST SHOD	
<u>Foot and ankle</u>	
↓ plantar flexor impulse or power (force production)	Limited (1 HQS[11] and 1 MQS[6])
↓ internal ankle plantar flexor moment during stance	Limited (1 LQS[7] and 1 MQS[6])
↓ Increased ankle contact forces	Very limited (1 LQS[7])
↑ average positive ankle power during stance	Very limited (1 MQS[6])

↓ plantar flexor impulse or power (force production)	Limited (1 HQS[11] and 1 MQS[6])
↓ internal ankle dorsiflexion moment during stance	Limited (1 LQS[7] and 1 MQS[6])
Lower leg/tibia	
↓ gastrocnemius and soleus muscle forces	Very limited (1 LQS[7])
↓ peroneal muscle forces	Very limited (1 LQS[7])
↑ tibialis anterior muscle forces	Very limited (1 LQS[7])
No difference in knee flexion/extension ROM	Limited (1 HQS[11])
Knee	
↑ knee power absorption	Very limited (1 MQS[6])
↑peak and average knee extensor moment	Very limited (1 MQS[6])
EFFECT OF CUES TO TRANSITION FROM RFS TO FFS WHILST BAREFOOT	
Spatio-temporal	
↑ distance from foot strike point to centre of mass	Very limited (1 MQS[1])
No change to centre of mass vertical displacement	Very limited (1 MQS[1])#
No change in step rate	Very limited (1 MQS[1])
Ground reaction forces	
↓ VALR	Limited (1 MQS[1] and 1 LQS[12])#
↓ VILR	Very limited (1 MQS[1])
↓ contact time	Very limited (1 MQS[1])
No change to total lower limb stiffness	Very limited (1 MQS[1])#
Foot and ankle	
↑ ankle PF at foot strike	Very limited (1 MQS[1])
Lower leg/tibia	
No change in damping coefficient (i.e. reduced ability to attenuate impact)	Very limited (1 MQS[9])#
↓ peak tibial acceleration	Very limited (1 LQS[12])#
↑ pre-activation of gastrocnemius	Very limited (1 MQS[1])
↑ stance phase activation of gastrocnemius	Very limited (1 MQS[1])
↓ pre-activation of tibialis anterior	Very limited (1 MQS[1])
↓ stance phase activation of tibialis anterior	Very limited (1 MQS[1])

<u>Knee</u>	
↑ knee flexion at foot strike	Very limited (1 MQS[1])#
↑ pre-activation of rectus femoris	Very limited (1 MQS[1])
<u>Hip</u>	
↓ hip flexion at foot strike	Very limited (1 MQS[1])#
↓ hip flexion/extension ROM	Very limited (1 MQS[1])
EFFECT OF CUES TO TRANSITION FROM NATURAL FFS TO RFS WHILST BAREFOOT	
<u>Foot and ankle</u>	
↓ vertical and overall curvature strain of the arch	Limited (1 HQS[11])^
<u>Lower leg/tibia</u>	
↓ plantar flexor impulse (force production)	Limited (1 HQS[11])
<u>Knee</u>	
No difference in knee flexion/extension ROM	Limited (1 HQS[11])

ALR = anterior loading rate, GRF = ground reaction force, HQS = high quality study, LQS = low quality study, MQS = moderate quality study, PFJ = patellofemoral joint, ROM = range of motion, VALR = vertical average loading rate, VILR = vertical instantaneous loading rate, VIP = vertical impact peak

differs from shod findings

^ measured only in barefoot condition

Table Biomechanical findings related to altering strike pattern (n = 9)

Study (year)	**Study design**	**Sample**	**Outcome measures**	**Intervention**	**Significant Biomechanical results**
Strike pattern altered in shod condition					
Willson (2015)[10]	Randomised cross-over design Treadmill running at PRS (2.84 +/- 0.22 m/s)	20 healthy (10 M, 10 F) runners aged 18-35 Primarily RFS runners Running at least 16 km/week	Per step and accumulative PFJ-RF Per step and accumulative PFJ-S	6 conditions, including PSR and +/- 10% PSR – each combined with RFS and FFS pattern	↓ PFJ-RF and PFJ-S (10%) ↓ accumulative PFJ-RF and PFJ-S Per step: Increasing step rate had a greater effect on ↓PFJ-S than transition from RFS to FFS (16 V 10%) Accumulative load: Transition from RFS to FFS had a greater effect on ↓PFJ-S than increasing step rate (10 V 7%)
Valenzuela [4](2015)		21 healthy (11 M, 10 F) runners able to run 5 km in 30 minutes or less 11 habitual RFS and 10 habitual FFS	Sagittal plane kinematics and kinetics	Transition from habitual strike pattern to alternate strike pattern	↑ peak VGRF with FFS ↑ DF ROM with transition to FFS ↑ internal ankle PF moments during mid to late stance with FFS ↓peak internal ankle DF moment with FFS ↓ internal knee extensor moment with FFS ↓ knee and hip ROM with FFS
Vannatta (2014)[3]	Randomised cross-over design Overground running between 3.52 and 3.89 m/s	17 healthy female runners running at least 16 km per week	PFJ-RF and PFJ-S Muscle forces (quadriceps, hamstring, gastrocnemious, and soleus) Knee flexion Step length	Transition from rearfoot to forefoot strike pattern	↓ PFJ-RF and PFJ-S ↑ VGRF ↑ gastrocnemius and soleus and muscle force ↓ quadriceps and hamstring muscle force

			Reach (horizontal distance from greater trochanter to heel marker)		↑ knee flexion at initial contact ↓ knee flexion ROM ↓ Reach No difference in step length
Landreneau (2014)[8]	Randomised cross-over design Treadmill running at 2.46 m/s	14 healthy (6 M, 8 F) participants	Sagittal plane hip knee and ankle kinematics Lower limb EMG	Transition from rearfoot to forefoot strike pattern	↓ ankle DF at foot strike, midstance and toe off No difference in sagittal plane hip or knee kinematics, or ankle inversion/eversion ↓ tibialis anterior muscle activity ↑ medial gastrocnemius muscle activity No difference in lateral gastrocnemius, soleus, VMO, rectus femoris or hamstring muscle activity
Stearne (2014)[6]	Cross-over design (not randomised) Treadmill running at 3.33 m/s	16 (8 RFS and 8 FFS) male runners running an average of 89 km per week	Lower limb kinematics and kinetics Spatio-temporal measures	Transition from habitual to alternate strike pattern	<u>Transition from RFS to FFS</u> ↑ peak internal ankle IR and PF moments and ankle power production ↑ internal ankle internal rotation moment rate ↑ average negative ankle power during stance ↓ negative average knee power No difference in hip joint moments or power <u>Transition from FFS to RFS</u> ↓ peak ankle power production with transition from FFS to RFS

					↑ average positive ankle power during stance ↓ average ankle PF moment rate ↑ negative average knee power ↑average knee extensor moment rate ↓ peak internal knee extensor moment and power absorption No difference in hip joint moments or power
Rooney (2013)[7]	Within participant (habitual condition first) Over-ground running at preferred speed (RFS 4.25 +/- 0.26 m/s; FFS 4.36 +/- 0.23 m/s)	15 RFS and 15 FFS competitive runners, running at least 6miles and 3 days per week	Joint moments Muscle and joint forces	Transition from RFS to FFS; and FFS to RFS	No differences between the two groups when using the same strike patterns (i.e. each group able to successfully imitate the other) ↓ internal ankle dorsi-flexion moment during first 50% of stance with RFS ↓ internal knee extensor moment during the first 20-30% of stance with RFS ↓ gastrocnemius, soleus and peroneal forces; and ankle contact forces with RFS ↓ TA forces with FFS
Giandolini (2013)[13]	Randomised trial with 2 groups and a 3 month follow up Treadmill running at preferred speed (average	30 (22 M, 8 F) healthy rearfoot strike runners	3D GRF Impact at tibia, heel and 5th metatarsal measured with accelerometers	<u>Group 1</u> Transition to MFS <u>Group 2</u> Transition to minimalist footwear	<u>MFS group</u> No change to peak accelerations (impact) at the heel, tibia or metatarsals No change in loading rate Impact peak remained (therefore, not effective)

	or range not stated)				↓ preferred running speed <u>Minimalist footwear group</u> ↓ peak heel acceleration, and shock wave propagation velocity at 2 and 3 months ↓ in impact peak at 3 months No change in loading rate
Williams (2012)[5]	Within participant (habitual condition first), but with randomization between shod and barefoot Over-ground running at 3.35 m/s	20 (10 M, 10 F) experienced RFS runners Running at least 6 miles and 3 days per week	Lower limb kinematics and joint powers	Transition from RFS to FFS (and from RFS shod to barefoot)	↑ ankle dorsiflexion at footstrike with a RFS pattern No differences in sagittal plane hip or knee angles at initial contact ↑ ankle power absorption with FFS ↓ hip and knee power absorption with FFS ↓ total power absorption with FFS
Laughton (2003)[2]	Randomised within participant design	15 rearfoot runners	3D rearfoot and knee kinematics and kintetics Tibial accelerations Ankle, knee and leg stiffness COM excursion	Transition to RFS and FFS in shoes with and without foot orthoses	↑ in peak positive tibial acceleration with FFS ↑ peak vertical GRF with FFS No difference between RFS and FFS for vertical loading rates ↑ peak AP GRF and loading rate with FFS ↑ ankle inversion and PF at foot strike with FFS ↑ ankle eversion and dorsiflexion excursion with FFS

					↑ knee flexion at foot strike and reduced peak and excursion of knee flexion ↓ ankle stiffness, but greater knee and leg stiffness with FFS ↓ COM excursion with FFS
Kirby (1983)[14]	Within participant design Treadmill running at 2.24 m/s	14 runners (10 M and 4 F) with clinical features suggestive of anterior tibial compartment syndrome	Anterolateral fascial compartment pressures	Transition to RFS and FFS from undefined natural strike pattern	No significant differences in compartmental pressures between relaxed and FFS or relaxed and RFS
Strike pattern altered in shod and barefoot condition					
Enders (2014)[9]	Randomised within participant design Treadmill (1% incline) running at 3.5 m/s	12 healthy male runners Running 15 to 30km per week	Impact measured with accelerometers and used to calculate damping coefficient	Transition from RFS to FFS with and without footwear	↑ damping coefficient with FFS in footwear (i.e. reduced ability to attenuate impact) No differences between FFS and RFS in barefoot condition
Shih (2013)[1]	Counter-balacned cross-over within participant Treadmill running at 2.5 m/s	12 healthy male rearfoot strike runners	Lower limb muscle activity, sagittal plane kinematics, and stiffness COM displacement and distance from foot strike point	Transition from RFS to FFS with and without footwear	↑ pre-activation of RF and Gastrocs with FFS regardless of footwear ↑ stance phase activation of Gastrocs with FFS regardless of footwear ↓ pre-activation and stance phase activation of TA regardless of footwear ↓ average and maximal loading rate with FFS regardless of footwear ↓ contact time regardless of footwear

					No difference in step rate regardless of footwear (Nb: step rate increased with barefoot regardless of strike pattern) ↓ hip flexion at foot strike with FFS regardless of footwear ↑ plantar-flexion and knee flexion at foot strike regardless of footwear ↓ hip flexion-extension ROM regardless of footwear ↑ distance from foot strike point to COM with FFS regardless of footwear No difference in COM vertical displacement No difference in lower extremity stiffness
Perl (2012)[11]	Randomised within participant Treadmill running at 3.00 m/s	15 (13 M, 2 F) experienced barefoot or minimalist FFS pattern runners	Lower limb kinematics and kinetics Arch strain	Transition from FFS to RFS in 2 conditions (Standard shoes and VFF)	↑ plantar flexor impulse (force production) with FFS ↑ vertical and overall curvature strain of the arch with a FFS^ No difference in knee excursion between FFS and RFS
Strike pattern altered in barefoot condition					
Oakley (1998)[12]	Within participant (order unclear) Over-ground barefoot running at 3.3-3.6 m/s	18 (10 male, 8 female) mostly inexperienced runners (only 4 reported previous running experience)	Tibial accelerations GRF	Comparison of RFS and FFS (toe strike) whilst barefoot	↓ peak tibial acceleration in FFS ↓ loading rate of vertical GRF in FFS

* Based on same data set as Heiderscheidt (2011) – repeat results not summarised in Table

^ Measured in barefoot condition only

MFS = midfoot strike, V = Vibram Five Fingers

COM = centre of mass, EMG = electromyography, GC = gait cycle, GMed = gluteus medius, GRF = ground reaction force, LHam = lateral hamstrings, MG = medial gastrocnemius, MHam = medial hamstrings, PFJ = patellofemoral joint, PSL = preferred stride length, PSR = preferred step rate, RF = rectus femoris, TA = tibialis anterior, VIP = vertical impact peak, VILR = vertical instantaneous loading rate, VALR = vertical average loading rate, VL = vastus lateralis, 2D = two dimensional, 3D = three dimensional

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