Supplementary file 8 Biomechanical effects of modifying impact loading variables, contact time, stiffness, and combined interventions

FINDINGS	LEVEL OF EVIDENCE
CUES TO REDUCE IMPACT LOADING VARIABLES	
<u>Ground reaction forces</u>	
↓ VALR and VILR following intervention	Limited (1 HQS[1]* and 1 LQS[2])
Conflicting findings for VALR, VILR and impact peak at one month follow up	1 HQS[1]* = no change; 1 LQS[2] = ↓
No change in impact peak following intervention^	Limited (1 HQS[1]* and 1 LQS[2])
<u>Foot and ankle</u>	
↓ dorsiflexion at foot strike following intervention and at 1 month follow up	Limited (1 HQS[1]*)
<u>Tibia</u>	
↓ peak tibial acceleration following intervention and at 1-4 week follow up	Limited (1 HQS[1]*, 1 MQS[3] and 1 LQS[2])
No difference in ↓ peak tibial acceleration between visual and verbal feedback at 1 week follow up	Very limited (1 MQS[3])
<u>Knee and hip</u>	
No changes in hip or knee sagittal plane kinematics	Limited (1 HQS[1]*)
CUES TO TRANSITION FROM REARFOOT TO FOREFOOT STRIKE AND INCREASE STEP RATE	
<u>Spatio-temporal</u>	
↓ contact time	Very limited (1MQS[4])
↓ in peak vertical GRF, impulses, and weight acceptance rates	Very limited (1MQS[4])
CUES TO TRANSITION FROM REARFOOT TO FOREFOOT STRIKE AND ALTER PROXIMAL MECAHNICS (MORE UPRIGHT TRUNK, INCREASED HIP FLEXION	
<u>Spatio-temporal</u>	
↓ stride length	Very limited (1 MQS[5]
<u>Foot and ankle</u>	
↓ ankle dorsiflexion at foot strike	Very limited (1 MQS[5]
↓ tibial angle (i.e. more vertical)	Very limited (1 MQS[5]
<u>Hip</u>	
↑ peak hip flexion angle	Very limited (1 MQS[5]
CUES TO REDUCE CONTACT TIME	
<u>Spatio-temporal</u>	
↓ centre of mass vertical displacement	Very limited (1 MQS[6])
<u>Ground reaction forces</u>	

↑ leg stiffness	Very limited (1 MQS[6])
↑ peak vertical GRF	Very limited (1 MQS[6])

GRF = ground reaction force, HQS = high quality study, LQS = low quality study, MQS = moderate quality study, VALR = vertical average loading rate, VILR = vertical instantaneous loading rate

* Comparison made against a control group

^ Crowell (2011) indicates a trend ($p = 0.06$) for reduction

Table Findings related to strategies to reduce impact

Study (year)	Study design	Sample	Outcome measures	Intervention	Significant Biomechanical results
Visual and audio feedback					
Creaby (2015)	Randomised comparison trial Running at 3 m/s	22 healthy male runners aged 18-45 Running at least 10 km/week	PTA	Group 1 (n =11) 10 minutes of clinician guided **verbal** feedback – "run softer" Group 2 (n = 11) 10 minutes of tibial accelerometer guided **visual** feedback – reduce tibial accelerations	↓ PTA in both groups with no difference between groups Changes maintained for 10 minutes after feedback and at 1 week follow up
Clansey (2014)[1]	Randomised controlled trial Over-ground running at 3.7 m/s	29 (22 completed study) rearfoot striking male runners Running at least 30 km per week PTA > 9g	Triaxial accelerometer (attached to anteromedial tibia) IP, VILR, VALR, PTA Sagittal plane hip, knee and ankle kinematics	Group 1 3 weeks (6 20 minute sessions) of visual and audio feedback (every 5 steps) to reduce PTA to < 50% of baseline during treadmill running Group 2 Same testing and running protocol without feedback	↓ PTA compared to control group following intervention and at 1 month follow up ↓ VALR compared to control group following intervention ↓ VILR compared to control group following intervention No changes in impact peak ↑ PF at foot strike following intervention and at 1 month follow up No changes in hip or knee sagittal plane kinematics

					No changes in running economy
Visual and verbal feedback					
Crowell (2011)[2]	Case series Over-ground running at 3.7 m/s	10 rearfoot strike runners (4M and 6 F) Running at least 16 km per week PTA > 8g	Triaxial accelerometer (attached to anteromedial tibia) IP, VILR, VALR, PTA	2 weeks (8 sessions) of visual and verbal ("run softer") to reduce PTA to < 50% of baseline during treadmill running	↓ PTA following intervention and at 1 month follow up ↓ VALR following intervention and at 1 month follow up ↓ VILR following intervention and at 1 month follow up Impact peak ↓ at one month follow up and similar trend immediately following intervention (p = 0.06)

F = females, GRF = ground reaction force, M = males, PSW = preferred step width, SW = step width, VALR = vertical average loading rate, VILR = vertical instantaneous loading rate

PTA = peak tibial acceleration

Table Findings related to combined and other strategies

Study (year)	Study design	Sample	Outcome measures	Intervention	Significant Biomechanical results
Combination of transition from rearfoot to forefoot or midfoot strike with proximal strategies					
Diebal (2012)[4]	Case series Immediate post intervention follow up only (clinical for 12 months) Treadmill running at preferred speed (not reported)	10 military personnel diagnosed with compartment syndrome and indicated for surgery (fasciotomy) by an orthopaedic surgeon	Spatio-temporal characteristics (step length, step rate and support time) Vertical GRF	6 weeks of visual (video) and verbal feedback to transition from RFS to FFS and increase step rate toward 180 per minute	↓ step length ↑ step rate (163 to 172) ↓ contact time ↓ in peak vertical GRF, impulses, and weight acceptance rates

Breen (2015)[5]	Case series Immediate post intervention follow up only (clinical for 12 months) Treadmill running at PRS	10 runners (9 M, 1 F) presenting to sports medicine clinic with anterior ELLP	2 dimensional lower limb kinematics using high speed video camera	6 weeks of Individualised feedback to reduced ankle DF at foot strike (options included instructing MFS, increasing hip flexion, promoting earlier push off, and running more upright) Retraining completed independently, 3 sessions per week with 2 follow up sessions	↓ ankle DF at foot strike ↓ tibial angle (i.e. more vertical) ↑ peak hip flexion angle ↓ stride length
Instruction to alter contact time					
Morin (2007)[6]	Treadmill running at 3.33 m/s	10 healthy male runners	Vertical GRF, COM vertical displacement, and leg stiffness	Increase and decrease contact time at fixed velocity and step rate (verbally asked to make as large a change as possible)	↓ COM vertical displacement with reduced contact time ↑ leg stiffness with reduced contact time ↑ peak vertical GRF with reduced contact time
Combination of various cues					
Messier (1989)	Randomised controlled trial Treadmill running at 2.0 m/s	22 female runners possessing at least one of excessive vertical oscillation of the COG, trunk and arm rotation, trunk flexion or extension; lack of arm movement; extreme elbow joint angle (i.e. holding the arms too high or too low); under- or over-striding; or	Stride length/height ratio and contact time Ankle PF at toe-off Peak ankle dorsiflexion and knee flexion Average elbow angle and trunk inclination COM vertical oscillation	Retraining group (n = 11) 5 weeks (15 sessions of 20 minutes) of visual (video) and verbal feedback during treadmill running to encourage a defined running action^ Control group (n = 11) 5 weeks (15 sessions of 20 minutes) of treadmill running without feedback	↓ support time in intervention group ↑ stride length in intervention group ↓ ankle PF during toe off in retraining group ↑ knee flexion during stance and swing ↑ vertical oscillation of COM in intervention group ↓ DF during stance in both GROUPS

	minimal knee flexion or extension	

EELP = exertional lower leg pain, F = females, GRF = ground reaction force, M = males, PSW = preferred step width, SW = step width, VALR = vertical average loading rate, VILR = vertical instantaneous loading rate, PTA = peak tibial acceleration

^ Defined running action from Messier (1989) = "(a) a slightly flexed trunk, (b) arms held at a 90 degree angle without coming across the body's midline, (c) flexion of the hip, knee and ankle following footstrike, (d) running from heel to toe (rearfoot striker), (e) extension of the hip at toe-off, (f) flexion of the knee of the non-support leg during the swing phase and (g) small vertical oscillations of the COG."

1. Clansey AC, Hanlon M, Wallace ES, et al. Influence of tibial shock feedback training on impact loading and running economy. Med Sci Sports Exerc 2014;**46**(5):973-81.
2. Crowell HP, Davis IS. Gait retraining to reduce lower extremity loading in runners. Clinical Biomechanics 2011;**26**(1):78-83.
3. Creaby MW, Franettovich Smith MM. Retraining running gait to reduce tibial loads with clinician or accelerometry guided feedback. J Sci Med Sport 2015.
4. Diebal AR, Gregory R, Alitz C, et al. Forefoot running improves pain and disability associated with chronic exertional compartment syndrome. Am J Sports Med 2012;**40**(5):1060-7.
5. Breen DT, Foster J, Falvey E, et al. Gait re-training to alleviate the symptoms of anterior exertional lower leg pain: a case series. Int J Sports Phys Ther 2015;**10**(1):85-94.
6. Morin JB, Samozino P, Zameziati K, et al. Effects of altered stride frequency and contact time on leg-spring behavior in human running. J Biomech 2007;**40**(15):3341-8.