ACUTE EFFECTS OF BAREFOOT RUNNING ON LOWER LIMB KINEMATICS AND SPATIOTEMPORAL VARIABLES IN HABITUALLY SHOD MALES

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The aim of this study was to examine the immediate effects of barefoot running on lower limb joint kinematics and stride patterns in a group of habitually shod runners. Ten male runners performed 1 minute bouts of treadmill running at 3 fixed velocities in both shod and barefoot conditions. 2D video kinematic data were recorded and 6 discrete markers were digitized in order to quantify ankle, knee and hip kinematics. Synchronous kinetic data were recorded from a force plate supporting the right posterior treadmill leg in order to quantify spatiotemporal variables. BF running resulted in significantly higher stride frequency and shorter ground contact times. In addition, BF running significantly reduced knee and hip but increased ankle range of motion during the absorptive phase of the stance. The results highlight that running mechanics can change in as little as 30 seconds of BF running.

KEY WORDS: 2D joint kinematics, stride frequency, velocity

INTRODUCTION: The last decade has seen a remarkable increase in the interest and participation in barefoot (BF) or minimalist running. This interest was primarily driven by claims that BF running alters stride mechanics resulting in a more forefoot strike pattern, which attenuates impact forces and may ultimately reduce the risk of long-term injury (Lieberman, Venkadesan, Werbel, Daoud, D'andrea, Davis, Mang'Eni & Pitsiladis, 2010; Robbins & Hanna, 1987). A significant body of research has previously described the effects of BF running on kinetics (De Wit, De Clercq & Aerts, 2000; Squadrone & Gallozzi, 2009), footstrike pattern (Lieberman et al., 2010) and more recently 3D joint kinematics (Bonacci, Saunders, Hicks, Rantalainen, Vicenzino & Spratford, 2013) and running economy (Perl, Daoud & Lieberman, 2012). However, much of this published research has used habitually BF runners (Lieberman et al., 2010, Squadrone & Gallozzi, 2009, Perl et al., 2012). Other studies using habitually shod participants often performed a pre-trial familiarization period in order to provide time for runners to adjust their recruitment patterns (De Wit et al., 2000; Bonacci et al., 2013). Additionally, many of these studies have examined BF running at single velocities (Bonacci et al., 2013; Lieberman et al., 2010; Squadrone & Gallozzi, 2009). While there is general agreement that BF running alters both joint kinematics and kinetics during the stance phase of the stride cycle, there is little or no evidence as to whether these alterations are immediate. Therefore, the primary objective of this study was to examine the acute effect of BF running on a group of habitually shod runners. A secondary aim was to compare the effect of velocity across shod and BF conditions.

METHODS: Ten healthy, male recreational runners (age 24 ± 3 yr, height 1.79 ± 0.07 m, body mass 75.1 ± 9.5 kg, >180mins.wk^{-1} running) with no experience of barefoot running volunteered for this study. Subjects ran in a randomized trial order at 3 fixed velocities (V_1=3.13, V_2=3.80 and V_3=4.47 m.s^{-1}, respectively) on a motorized treadmill in two running conditions (barefoot and shod). Duration of each trial was 1 minute, with 5 minutes recovery between trials. Subjects performed a 10min warm-up at self-selected pace in their normal running shoes. Reflective markers were positioned at 5 locations on the right leg of each subject at the following anatomical landmarks: a) 5th metatarsal head; b) lateral malleolus; c) lateral calcaneus; d) lateral femoral condyle; e) trochanter major. An additional marker was placed on the right angle of the mandible to assess vertical displacement. Sagittal plane kinematics were recorded at 60Hz with a 0.001s shutter during the final 30s of each trial. Synchronous kinetic data were recorded from an embedded force place (Kistler) which supported the right posterior leg of the treadmill; facilitating the identification of initial contact (IC) and toe off (TO). Markers were digitized, transformed using 2D direct linear transformation (DLT), and digitally filtered at 10Hz using APAS 2011 software. Data were subsequently transferred to Matlab and processed using customized algorithms. Joint angles from the ankle, knee and hip were averaged over 10 consecutive stride phases for each trial. Spatiotemporal variables of interest were stride frequency, stride duration, absolute (ms) and normalized (% of stride cycle) ground contact time (GCT). Kinematic variables of interest were ankle, knee and hip angle at IC, TO and range of motion (ROM) during absorptive phase of the stance. In addition, time to peak knee flexion was quantified in order to establish duration of absorptive phase. Finally, vertical displacement was analysed from the 6th marker at the mandible. Normality was assessed using Kolmogorov-Smirnov tests and statistical analysis was performed using 2 factor (condition x speed) repeated measures ANOVA, Tukey post-hoc tests quantified differences within interactions ($P<0.05$ inferring statistical significance).

Table 1: Spatiotemporal variables of the stride cycle
(# infers significant difference between conditions)

Variable	Velocity	Barefoot	Shod
Stride Frequency (strides.min^{-1})	V_1	87.3 (4.7)$^{\#\#}$	85.1 (4.7)
	V_2	91.6 (4.9)$^{\#\#\#}$	87.6 (5.9)
	V_3	96.1 (5.5) $^{\#\#\#}$	92.4 (6.1)
Stride duration (ms)	V_1	689 (34)$^{\#\#}$	707 (38)
	V_2	656 (34)$^{\#\#\#}$	688 (46)
	V_3	626 (33)$^{\#\#\#}$	651 (44)
Absolute GCT (ms)	V_1	220 (19)	225 (19)
	V_2	197 (15)$^{\#\#}$	206 (18)
	V_3	178 (18)$^{\#\#}$	188 (15)
Normalised GCT (% of stride cycle)	V_1	32.0 (2.2)	31.9 (2.0)
	V_2	30.1 (2.1)	29.9 (1.9)
	V_3	28.5 (2.4)	29.1 (2.0)

RESULTS: Significant alterations in both lower limb joint kinematics and spatiotemporal variables were observed comparing BF and shod running. Overall, stride frequency was significantly higher and stride duration significant shorter in BF. In addition, GCT was significantly shorter in BF; however when GCT was normalized to stride duration, no difference between conditions was observed (see Table 1). As expected, velocity had a significant effect on stride frequency ($P<0.001$), stride duration ($P<0.001$) and both absolute and normalized GCT ($P<0.01$). With regards to kinematic variables, BF running resulted in significantly greater plantar flexion ($P<0.01$ at all velocities) and knee flexion ($P<0.05$ at V_1) at IC, greater ankle ROM during the absorptive phase ($P<0.05$ at all velocities), reduced knee ($P<0.001$ at all velocities) and hip ROM ($P<0.01$ at all velocities) during the absorptive phase, and greater plantar flexion at TO ($P<0.05$ at all velocities); see table 2. Velocity significantly increased plantar flexion ($P<0.05$ for both BF and shod) and hip extension at TO (P<0.05 in both BF and shod), and significantly increased hip (P<0.05 for BF, P<0.01 for shod) and knee flexion at IC (V_3 vs. V_1; P<0.05 for both BF and shod).

Table 2: Joint kinematic data

(# infers significant overall condition effect; * infers significant overall velocity effect)

		V_1		V_2		V_3	
		BF	Shod	BF	Shod	BF	Shod
Ankle							
Angle at IC (°)	###	-4 (5)	-1 (6)	-6 (4)	-3 (5)	-5 (6)	-2 (5)
Angle at TO (°)	# ***	-14 (5)	-18 (6)	-19 (6)	-10 (7)	-15 (6)	-15 (7)
ROM (°)	## *	23 (4)	20 (5)	26 (4)	22 (5)	26 (5)	21 (4)
Knee							
Angle at IC (°)	# **	19 (5)	17 (6)	21 (5)	18 (6)	22 (5)	19 (5)
Angle at TO (°)		23 (4)	22 (2)	22 (4)	22 (7)	23 (3)	23 (7)
ROM (°)	###	23 (4)	28 (3)	22 (3)	28 (2)	23 (5)	28 (2)
Time to peak (%)	#	38 (4)	41 (5)	36 (3)	40 (6)	38 (3)	41 (6)
Hip							
Angle at IC (°)	***	32 (4)	32 (7)	34 (4)	34 (7)	36 (6)	37 (7)
Angle at TO (°)	***	-2 (3)	-2 (6)	-5 (3)	-5 (6)	-7 (3)	-5 (6)
ROM (°)	##	2 (1)	4 (1)	1 (1)	3 (1)	1 (1)	3 (1)
Head Marker							
Vertical Disp. (cm)	### ***	6.4 (0.9)	6.7 (0.9)	5.7 (0.8)	6.2 (0.9)	5.0 (0.9)	5.6 (1.3)

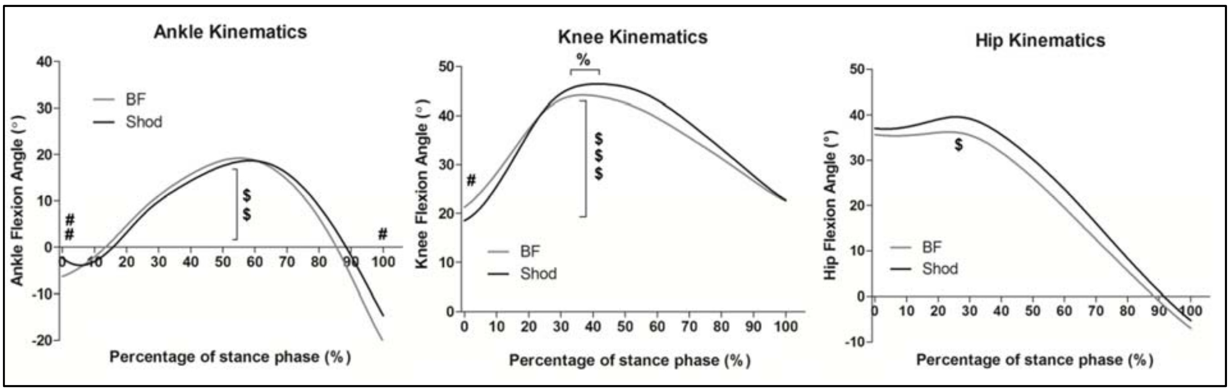

Figure 1: Group mean joint kinematics at V_3. # indicates significant difference between conditions at IC or TO. $ indicates significant difference in ROM. % indicates significant difference in time to peak flexion.

DISCUSSION: As little as 30s of BF running resulted in alterations to both the spatiotemporal variables of the stride and the joint kinematics of the ankle, knee and hip during the stance phase and these differences were for the most part consistent across all velocities. The alterations included increased stride frequency, reduced GCT, reduced knee and hip ROM during the absorptive phase and reduced vertical displacement. The increased stride frequency observed during BF running has been observed by many researchers (De Wit et al., 2000, Bonacci et al., 2013) and most likely played a role in significantly reducing the vertical displacement (Farley & Gonzalez, 1996). Ankle and knee kinematics observed during BF running are also in agreement with previous research reporting increased plantar flexion and knee flexion at IC for BF conditions (De Wit et al., 2000, Bonacci et al., 2013). Reduced knee and hip ROM during the absorptive phase highlights increased leg stiffness during BF running, which is also in agreement with previous literature (De Wit et al., 2000). It is also likely that increased stride frequency played a direct role in altering knee and hip kinematics, resulting in this increased leg stiffness (Farley & Gonzalez, 1996). Interestingly, time to knee flexion was significantly shorter during BF running, suggesting that runners spend less time in the absorptive or “braking” phase and more time in the propulsive phase of the stance. In contrast to the hip and knee ROM, BF running significantly increased ankle ROM during the absorptive phase of the stance. It therefore appears that in less than 1 minute of BF running an individual will increase absorption of impact forces at the ankle via an increase in planterflexion and ROM, which immediately reduces the demand for absorption of forces from the proximal joints (knee and hip).

CONCLUSION: The main finding of the current study is that habitually shod runners significantly alter their stride pattern and joint kinematics in as little as 30 seconds of barefoot running, with no prior familiarization. These differences appear independent of velocity. The findings highlight the rapid adjustments that can be made to running pattern and joint kinematics, brought about by acute awareness of altered impact forces by the tactile receptors in the foot and proprioceptive organs in the shank. It appears that even runners with no previous barefoot running experience can rapidly adjust their mechanics in response changes underfoot.

REFERENCES:

De Wit, B., De Clercq, D. and Aerts, P. (2000). Biomechanical analysis of the stance phase during barefoot and shod running. *Journal of Biomechanics* 33, 269-278

Lieberman, D., Venkadesan, M., Werbel, W., Daoud, A., D’andrea, S., Davis, I., Mang’Eni, R. and Pitsiladis, Y. (2010). Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature* 463, 531-535.

Bonacci J, Saunders PU, Hicks A, Rantalainen T, Vicenzino BG and Spratford W. (2013). Running in a minimalist and lightweight shoe is not the same as running barefoot: a biomechanical study. *British journal of sports medicine*. 47(6), 387-92

Squadrone R and Gallozzi C. (2009). Biomechanical and physiological comparison of barefoot and two shod conditions in experienced barefoot runners. *The Journal of sports medicine and physical fitness*. 49 (1). 6-13.

Robbins, S., and Hanna, A. (1987). Running-related injury prevention through barefoot adaptations. *Medicine and Science in Sports and Exercise*, 19 (2),148-156.

Farley, C. & Gonzalez, O. (1996). Leg stiffness and stride frequency in human running. *Journal of Biomechanics*. 29 (2), 181 – 186.

Perl, D., Daoud, A. and Lieberman, D. (2012). Effect of footwear and strike type on running economy. *Medicine and Science in Sports and Exercise.* 44 (3), 1335 – 1343.