BAREFOOT AND SHOD RUNNING WITH DIFFERENT STRIKE PATTERNS: A KINETIC ANALYSIS

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The purpose of this study was to determine, if running barefoot versus shod conditions over ground has any impact on kinetic variables of forefoot/mid-foot (FF/MF) versus rearfoot (RF) strike patterns. Ten men between the ages of 18 and 22 were recruited. All subjects performed five 20m runs, in each condition, over force platforms. Peak horizontal force and impulse were obtained from both braking and propulsive periods as well as peak vertical force. Results include: peak vertical force for the RF pattern in barefoot running was higher than all other conditions ($p < 0.01$), higher braking impulses in the RF pattern in both conditions, particularly barefoot ($p < 0.01$), and higher propulsive impulses in FF pattern in both conditions ($p < 0.01$). It is concluded that the most differences are found between strike patterns rather than between barefoot and shod running.

KEY WORDS: foot strike patterns, running, impulse, barefoot, shod.

INTRODUCTION: Running is a popular and fundamental movement that many healthy, active individual perform. Running enthusiasts have different preferences such as running with or without shoes and using various strike patterns. Barefoot running has emerged as a controversial topic; eliciting a plethora of scientific literature and research. Its advocates argue that this practice is commonly associated with a forefoot (FF) or mid-foot strike (MF) which may reduce the risk of knee injury and is more economically favorable than shod running which tends to exhibit a rear-foot strike (RF) pattern (Divert, Mornieux, Baur, Mayer & Belli, 2005; Hanson, Berg, Deka, Meendeering & Ryan, 2011; Lieberman, Venkdesan, Werbal, Daoud, D'Andrea, Davis & Pitsiladis, 2010; Shih, Lin, & Shiang 2013). However, other studies have reported no significant differences in running economy between running with and without shoes (Gruber, Umberger, Braun & Hamill, 2013; Perl, Daoud & Lieberman., 2012).

Gruber et al. (2013) found that habitual FF and RF runners had no significant difference in running economy. As runners switched to an alternative striking technique, greater oxygen consumption was found for both groups during high speed running, but only in the RF group at low and medium speeds. Furthermore, the study suggested that during shod running FF/MF strike patterns may not be as economical as a RF pattern (Gruber et al., 2013). In contrast, Perl et al. (2012) determined that minimalist shoes, which showed no significant differences from barefoot conditions, have a lower cost of transport (COT) for both FF and RF, when compared to shod. In addition, there seemed to be no COT differences between FF and RF strike patterns within each the barefoot or shod conditions, which are contradictory to Gruber et al. (2013) results.

In reality, the majority of runners, ~75%, utilize a RF pattern and many switch strike technique throughout a race (Bakkie et al., 2013; Hasegawa et al., 2007; Larson et al., 2012). In order to maintain velocity, runners utilize both striking techniques to optimize running economy. It has been shown that there is a proportional relationship between vertical ground reaction force (GRF) and metabolic cost which is considered a major determinate of the metabolic cost of running (Chang & Kram, 1999). Additionally, Chang and Kram (1999) determined that horizontal propulsive impulses during normal running accounted for 33% of metabolic economy, determining that horizontal forces are four times more costly than vertical forces. In order for a runner to maintain steady-speed running on a flat surface, propulsive impulses must equal braking impulses (Nigg, 1986); therefore the higher the braking impulse the higher the subsequent propulsive impulse, which indicates higher metabolic demand (Chang & Kram, 1999). While previous literature focused on running economy, there is limited research examining running kinetics factors as well as determining if mechanical efficiency aligns with metabolic economy.

Therefore, the purpose of this study was to determine if running barefoot versus shod conditions had any impact on mechanical factors of FF/MF versus RF strike patterns. We hypothesized that: 1) a lower peak horizontal GRF will be observed in barefoot conditions in both FF and RF when compared to shod, 2) a greater peak vertical GRF will be observed in RF compared to FF, particularly in barefoot conditions, and 3) higher braking and propulsive impulses will be observed in shod running.

METHODS: Ten male college students between the ages of 18 and 22 (BH = 1.84 ± 0.03m; BM = 78.92 ± 8.48kg) were recruited from northern California. All subjects met the ACSM requirements for highly active classification, had no prior barefoot running experience, and no current injuries reported. Six subjects reported being RF runners, two subjects reported being MF runners, and two subjects did not know their preferred/natural strike pattern. All policies and procedures for the use of human subjects were followed and approved by the university Institutional Review Board.

Each subject was required to warm-up for at least five minutes by jogging and practicing striking the force platform. All subjects performed five 20m runs (time for the middle 10 m were obtained to control the average velocity at about 4-5m/s), in each condition (B-MF/FF, B-RF, S-MF/FF, S-RF; where B represents barefoot and S represents shod), over two force platforms (Kistler 9286; 1080 Hz). Each subject took a half minute break between each trial. Conditions were performed in random order. The trials were excluded and recollected when subject failed to strike any of the force plates with dominant leg and/or the average velocity was not met. In regards to shoe conditions each subject ran in their individually preferred running shoe which could be considered a 'typical running shoe': greater than 250g, and a raised heel of 12 mm or more.

All data were extracted from one stance phase of the dominant leg on the force platforms. Peak horizontal ground reaction force (Fy anterior-posterior) and impulse were obtained from both braking and propulsive periods. Impulse was measured from the product of average Fy and duration (s) of the observed phase. Peak vertical ground reaction force (Fz vertical) was obtained for each strike as well. Two way ANOVA was performed to determine the difference for each variable among the conditions and striking techniques. Tukey post hoc was applied to identify the significant differences between groups. All statistical significance was set at 0.05.

RESULTS: Two-way ANOVA statistics determined significant difference between conditions for all three variables (peak vertical force, F = 13.53, $p < 0.01$; peak horizontal force, F = 14.69, $p < 0.01$; horizontal impulse, F = 13.48, $p < 0.01$) and Tukey post hoc testing revealed specific significant differences between conditions during observed stance phase. Table 1 presents the difference between conditions for Peak vertical GRF. Results show that the B-RF condition elicited a higher peak vertical GRF compared to all other conditions ($p < 0.01$).

Table 1
Peak Vertical Force (BW)

	RF	**MF/FF**
Barefoot	3.38 ± .69 * • °	2.92 ± .24 *
Shod	2.89 ± .36 •	2.98 ± .30 °

Note: * - sig diff between RF and MF/FF, • - sig diff barefoot and shod, ° - sig diff interaction

Table 2 shows the results of peak horizontal force in braking (Br) and propulsive (P) phases of the strike, respectively. Results show that the RF pattern, in both barefoot and shod conditions, peak horizontal braking force was significantly higher than peak horizontal propulsive force ($p < .001$). Secondly, the results show a significantly greater propulsive peak horizontal force in the FF pattern in both barefoot and shod conditions when compared to the RF pattern ($p < .05$).

Table 2
Peak Horizontal Force (percent BW)
Horizontal Impulse (BW·s)

		Barefoot	**Shod**	**Barefoot**	**Shod**
RF	**Br**	.52 ± .11 *	.49 ± .09 *	.029 ± .006 * ^	.025 ± .006 * ^
	P	.42 ± .05 * °	.40 ± .04 * °	.024 ± .003 * °	.022 ± .003 * °
FF	**Br**	.51 ± .09	.49 ± .09	.026 ± .005	.026 ± .005
	P	.48 ± .05 °	.46 ± .06 °	.029 ± .003 °	.028 ± .003 °

Note: * - sig diff between Br & P for that condition, ° -sig diff between RF & FF for that condition, ^ - sig diff between barefoot and shod

Table 2 also displays the horizontal impulse results in braking (Br) and propulsive (P) phases of the stance phase, respectively. Results show that in the RF strike a significantly higher horizontal impulse in the braking phase is seen in both barefoot ($p < .001$) and shod ($p < .001$) conditions, with the barefoot condition being significantly higher than the shod condition ($p < .001$) – when compared to the propulsive phase. Comparing the strike pattern reveals a significantly higher propulsive impulse in the FF pattern for both barefoot ($p < .001$) and shod ($p < .001$) when compared to the RF pattern.

DISCUSSION: The peak vertical GRF findings indicate that the B-FF, S-FF, and S-RF conditions elicits a significantly lower vertical force compared to B-RF by about 40 to 50% of body weight. This reduction of peak vertical force in FF pattern during barefoot running is well supported (e.g. Divert et al., 2005). Interestingly, this reduction in peak vertical force was not observed when running shod between strike patterns. This may be due to the added cushion of a shoe, while running in a RF pattern, attenuates the peak vertical GRF as much as a FF pattern. The lower peak vertical GRF has been associated with reduction in running related injuries (e.g. Shih, Lin, & Shiang, 2013). As the majority of runners run in a RF pattern, and there seems to be no differences in FF pattern attenuation, it may be beneficial for runners to run shod to reduce peak vertical GRF and potentially reduce running related injuries.

With regard to the peak horizontal force and impulse, the RF pattern exhibits in both shoe condition - greater values in the braking phase than propulsive phase while FF pattern demonstrated no differences between phases. This implies that the RF pattern in both barefoot and shod condition slowed down the runners more than speeding up (Nigg, 1986). As the subjects in this study maintained a constant average velocity during testing we can assume that the subjects had to increase their horizontal propulsive impulse over the subsequent steps. Further research should be conducted to determine if this increase in horizontal propulsive impulse may indicate a greater metabolic cost for RF pattern while running with and without shoes (Chang & Kram, 1999).

More interestingly, when running barefoot with a RF pattern, it showed a significantly higher braking impulse compared to RF in shod condition, yet no significant differences in the subsequent propulsive phase. This demonstrates that a RF runner will experience greater braking forces while barefoot compared to while shod. This increased braking impulse will require the B-RF runner to generate higher propulsive impulses in order to maintain steady running speed; thus increasing the metabolic cost of running (Chang & Kram, 1999). On the other hand, the FF horizontal propulsive impulses were found higher in both barefoot and shod running when compared to propulsive phase in RF pattern. Furthermore we see no significant differences in braking and propulsive impulses for FF pattern, signifying that steady speed was achieved throughout the stance and may be easier to maintain. It seems to point out the advantage of FF technique but may also result in greater metabolic cost of running (Chang & Kram, 1999; Lieberman et al., 2010)

It is also important to note that while it appears that peak horizontal forces are similar regardless of barefoot versus shod conditions there appears to be significant differences between strike patterns within conditions. The results in Table 2 indicate similar peak braking forces between strike patterns but significantly higher peak propulsive forces in the FF pattern compared to RF pattern in both barefoot and shod conditions. In Table 3 we also see similar results in terms of horizontal propulsive impulses seen in the FF pattern across both barefoot and shod conditions. These higher propulsive impulses indicate a significant increase in metabolic cost of running at a steady speed in a FF pattern in both barefoot and shod conditions (Chang & Kram, 1999). This is contrary to Gruber et al. (2013)'s findings in which there was no significant differences in economy of running between habitual FF and RF runners. As the subjects in this study ran at a similar pace to the 'fast' pace observed in the study by Gruber et al. (2013), we can infer that perhaps there are other differences between these two strike patterns that may account for the equal overall metabolic cost observed by Gruber et al. (2013).

One important limitation of this study was that the data was derived from one stance phase on the force platform in the middle of the overall 10m run; while 10m velocity was controlled for by time, the velocity during one single stance phase was not accounted or controlled for. Furthermore as it was imperative the subjects strike the force platform with their dominant leg, subjects may have altered speed to accurately land their strike on the force platform.

CONCLUSION: For over ground running, RF pattern exhibited the highest peak vertical force while barefoot. Furthermore peak braking horizontal force and braking propulsive impulse in both barefoot and shod conditions were higher when compared to the propulsive phase in the RF pattern. Beyond this there were no observed kinetic differences between barefoot and shod conditions. As there seem to be no differences between barefoot and shod we would recommend runners to run shod regardless of preferred strike pattern.

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