Are Midfoot Strike Patterns Similar to Forefoot Strike Patterns when Running in Minimal Footwear?

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INTRODUCTION

Ground reaction forces during early stance vary greatly between runners with a rear-foot strike (RFS) pattern and those with a forefoot strike (FFS) pattern. The vertical ground reaction force of a RFS pattern is associated with an abrupt rise to peak early in stance (impact peak, IP) and a high rate of loading [1] and high rates of loading have been linked with a variety of running-related injuries [2]. Impact transients are often missing from a forefoot (FFS) strike pattern. Loading rates associated with this pattern are approximately half of those of a RFS pattern [3]. As FFS runners are less common, investigators sometimes combine this group with runners who land with a flat foot and are considered midfoot strikers (MFS), also a small subset of the running population. However, the mechanics of these two strike patterns have not been formally compared to each other. Therefore, the purpose of this ongoing study was to compare the impact peaks and loading rates of habitual RFS, MFS and FFS patterns. It was hypothesized that RFS patterns would be associated with the highest impact variables and FFS patterns would be associated with the lowest impact variables. It was also hypothesized that impact variables of a MFS would be significantly different from the RFS or FFS and fall between the two.

METHODS

As part of an ongoing study, 28 subjects (age: 38.0±11.2yrs; mass: 74.9±11.2kg; height: 1.78±0.07m) have been recruited to date. All subjects were un-injured for at least the 3 months prior to data collection and running a minimum of 10 miles/week in minimal footwear. This minimal footwear was a mix of true minimal footwear (no midsole) and partial minimal footwear (some cushioning from a minimal midsole). All subjects ran along a 30m runway at 3.13 m/s (±5%) wearing standard lab-provided true minimal shoes (Inov-8 Bare-X 200), landing on force plates (AMTI, Watertown, MA) embedded at its center. Each of the first five good foot strike patterns per subject were categorized and agreed upon by two trained reviewers using high speed (125fps) video of the lateral foot.

Ground reaction force (GRF) data collected at 1500Hz and processed with a 4^{th} order, 50Hz low-pass filter were used to calculate loading rates and impact peaks. Instantaneous loading rate (ILR) was calculated as the maximum instantaneous slope (loading rate) within the first 25% of stance where force > 25% max force (25%MF). Average loading rate (ALR) was determined as the average loading rate of the 8% of stance preceding the first sample with force>25%MF and a slope<20BW/s. The average loading rate region would be shortened to not use the first 3% of stance if originally included.

Due to the current small sample sizes per group and two subjects exhibiting a mixed foot strike pattern, variables of interest were assessed across foot strikes as opposed to across subjects. The Kruskal-Wallis test, or One-way ANOVA on ranks, was used as data were not normally distributed. Significance set at $p<0.05$.

Cushioning has been shown to result in increased impacts [4]. Thus, we conducted a subanalysis of impacts between those who habitually run in partial minimal shoes (hP_{MIN}) and those who habitually run in true minimal shoes (hT_{MIN}) when tested in true minimal shoes. These were compared using a Wilcoxon rank sum test.

RESULTS AND DISCUSSION

145 total steps were analyzed (88 **FFS**, 17 **MFS**, 35 **RFS**; Table 1). Initial loading differences are

apparent from the mean GRF curves for the foot strike patterns in Fig. 1.

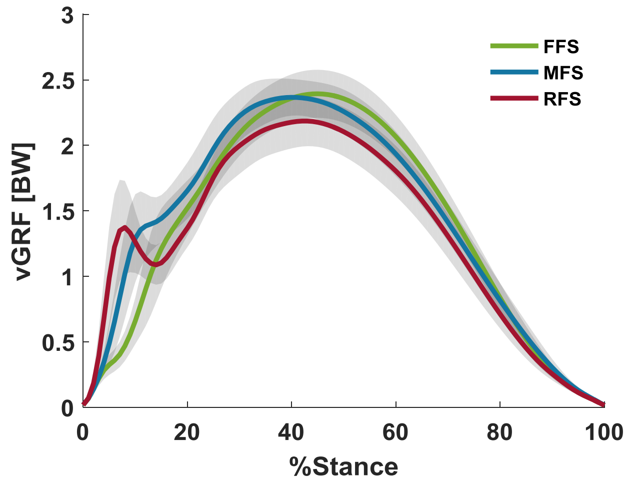

Figure 1: Mean vertical GRF (vGRF) for foot strike patterns.

Impact Peaks (IP) were present in 100% of all **RFS**, 47% of all **MFS**, and only 27% of all **FFS**. **MFS** vILR was significantly higher than **FFS** and significantly lower than **RFS** (Fig 2). Similar findings were noted for vALR (Table 1).

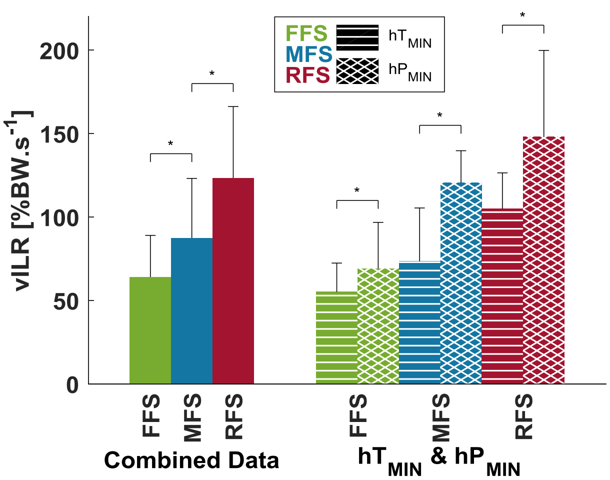

Figure 2: Mean vertical ILR (vILR) comparing combined habituated condition for foot strike type (Left) and comparing hT_{MIN} and hP_{MIN} within foot strike patterns (Right). Brackets indicate where differences were significant (p<0.05).

In each foot strike condition, runners who were habituated to partial minimal shoes (that have some cushioning) exhibited significantly higher loading rates than those habituated to true minimal footwear (Fig 2). This suggests that even a small amount of cushioning increases the tendency to land harder.

CONCLUSIONS

Preliminary analysis reveals that initial loading for MFS is significantly higher than that of a FFS. This suggests that combining these two patterns will result in higher impact variables than in FFS alone. Results also demonstrate that runners habituated to partial minimal footwear land harder than those habituated to true minimal footwear, even when using a similar foot strike pattern. This suggests that runners in these two types of footwear should also not be combined. Thus, results of this study suggest that both habituated footwear and foot strike matter when analyzing impacts in runners.

REFERENCES

1. Lieberman DE et al. *Nature* **463**, 531-535.
2. Davis IS, et al. *BJSM* [Epub ahead of print].
3. Kulmala JP, et al. *MSSE* **45**, 2306-2313.
4. Ruder MC, et al. *Proceedings of ACSM 2015*.

Table 1: Mean GRF values for variables considered. Two subjects (both hT_{MIN}) mostly FFS with 1 or 2 MFS. Values in parentheses standard deviations unless otherwise stated. ^p-value for foot strike. #p-value for habituated condition within foot strike.

		Unique Subjects	Fraction Steps w/ IP (%)	vILR [BW.s^{-1}]					p#	vALR [BW.s^{-1}]					p#
FFS	hT_{MIN}	8	3/33 (9.1%)	63.9(25.1)	p=0.03^		p<0.001^	55.2(17.3)	0.04	42.8(15.9)	p=0.01^		p<0.001^	37.2(13.0)	0.02
	hP_{MIN}	11	21/55 (38.2%)					69.2(27.7)						46.1(16.7)	
MFS	hT_{MIN}	3	3/12 (25%)	87.4(35.8)		p=0.03^		73.5(32.0)	0.02	61.1(22.0)		p=0.03^		51.7(18.9)	0.01
	hP_{MIN}	1	5/5 (100%)					120.6(19.2)						83.6(7.6)	
RFS	hT_{MIN}	4	20/20 (100%)	123.4(42.8)				105.0(21.5)	0.03	85.8(26.7)				74.1(13.3)	0.03
	hP_{MIN}	3	15/15 (100%)					148(51.8)						101.4(32.2)	

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Introduction

Motivation

- Ground reaction force (GRF) differences noted between foot strike patterns (FSP)
  - Rearfoot strike (RFS): abrupt rise to peak in early stance, high rates of loading[1,2]
  - Forefoot strike (FFS): impact transients often missing, lower rates of loading
- High rates of loading linked with a variety of running-related injuries[3]
- Midfoot strike (MFS; landing with a flat foot) often combined with forefoot strike runners due to small sample sizes
  - However, differences between MFS and FFS have not been compared.

Purpose

The purpose of this ongoing study was to compare the impact peaks and loading rates of habitual RFS, MFS and FFS patterns.

Hypothesis: loading rates lowest for FFS, higher for MFS, greatest for RFS

Methods

Subjects / Activity

- 28 subjects [age: 38.0±11.2yrs; height: 1.78±0.1m; mass: 74.9±11.2kg]
  - Uninjured >3 months prior to resting
  - Running >10miles/week in minimal footwear

Procedures / Analysis

- Ran along a 30m runway at 3.13m/s (±5%) in standard lab-provided true minimal shoes (Inov8 Bare-X 200)
- Forces plates (AMTI) embedded at center
- GRF collected at 1500Hz, processed with 4th order, 50Hz low pass filter
- Foot strike pattern categorized and agreed upon by 2 trained reviewers using 125fps digital video of the lateral foot
- Instantaneous loading rate (ILR): maximum instantaneous slope (loading rate) in first 25% stance where force >25% max force (25%MF)
- Average loading rate (ALR): Average slope of the 8% of stance preceding the first sample with force>25%MF and slope<20BW/s.
- Data NOT subject averaged before analysis
- One-way ANOVA on ranks used (data not normally distributed)
- **Subanalysis**: variables further assessed between those habituated to true minimal shoes versus partial minimal shoes.
  - True minimal footwear (no midsole; hT_{MIN})
  - Partial minimal (minimal midsole; hP_{MIN})

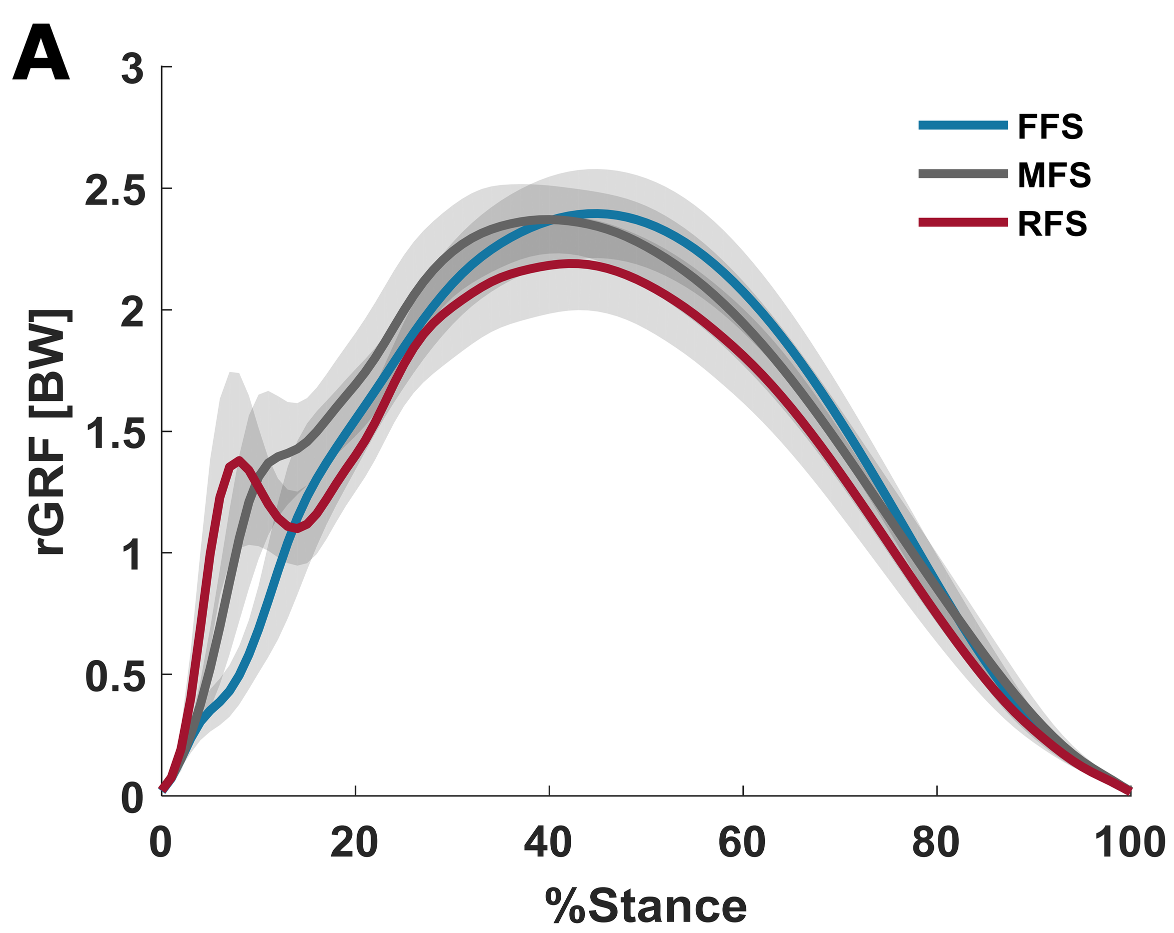

Fig A: Mean vertical GRF (vGRF) for foot strike patterns after time normalizing all stance phases.

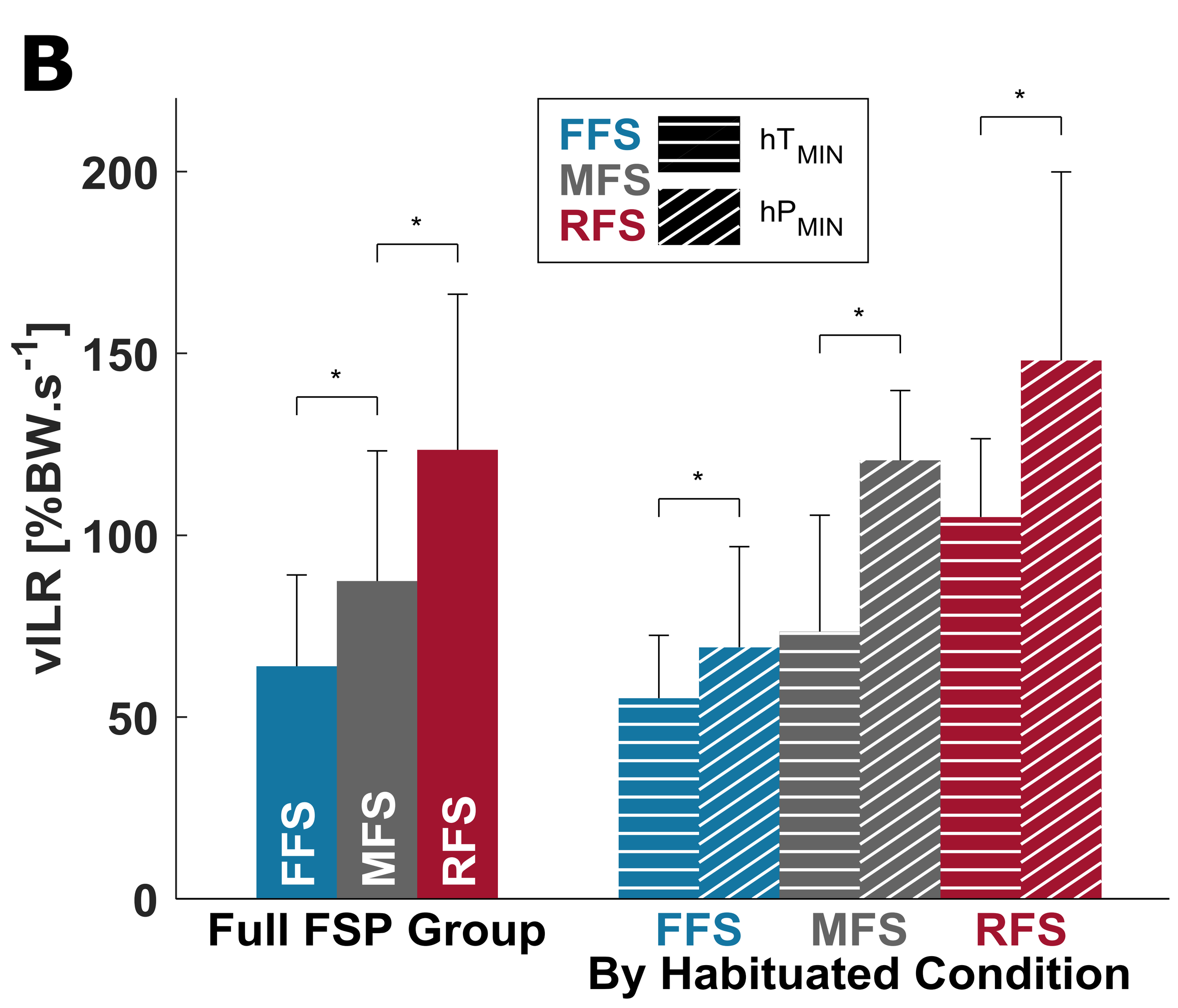

Fig B: Left: Mean vertical ILR (vILR) for each FSP group**. Right:** Mean vertical ILR (vILR) for FSP further stratified by habituated condition [true minimal shoes (hTmin) and partial minimal shoes (hPmin)]. Brackets indicate where differences were significant (p<0.05).

Table 1: Mean GRF values for variables considered. Two subjects with mixed FSP [both hT_{MIN}; subj1: 3FFS, 2 MFS; subj2: 4FFS, 1MFS]. Values in parentheses standard deviations unless otherwise stated. ^p-value for FSP comparisons. #p-value for habituated condition (HC) within FSP.

		FFS		MFS		RFS	
		hT_{MIN}	hP_{MIN}	hT_{MIN}	hP_{MIN}	hT_{MIN}	hP_{MIN}
Unique Subjects		8	11	3	1	4	3
Fraction Steps w/ IP (%)		3/33 (9.1%)	21/55 (38.2%)	3/12 (25%)	5/5 (100%)	20/20 (100%)	15/15 (100%)
vILR [BW.s-1]	all FSP	63.9(25.1)		87.4(35.8)		123.4(42.8)	
		p=0.03^ [FFS-MFS]					
				p=0.03^ [MFS-RFS]			
		p<0.001^ [FFS-RFS]					
	FSP + HC	55.2 (17.3)	69.2 (27.7)	73.5 (32.0)	120.6 (19.2)	105.0 (21.5)	148 (51.8)
		p=0.04#		p=0.02#		p=0.03#	
vALR [BW.s-1]	all FSP	42.8(15.9)		61.1(22.0)		85.8(26.7)	
		p=0.01^ [FFS-MFS]					
				p=0.03^ [MFS-RFS]			
		p<0.001^ [FFS-RFS]					
	FSP + HC	37.2 (13.0)	46.1 (16.7)	51.7 (18.9)	83.6 (7.6)	74.1 (13.3)	101.4 (32.2)
		p=0.02#		p=0.01#		p=0.03#	

Results

145 steps analyzed (88 FFS, 17 MFS, 35 RFS)

- Differences clear in average curves (**Fig A**)
- Impact peaks (IP) present in:
  - 27% **FFS**; 47% **MFS**; 100% **RFS**
- Vertical Loading Rates (vILR & vALR):
  - **FFS** < **MFS** < **RFS** (**Fig B**; **Table 1**)
  - $hP_{MIN} > hT_{MIN}$ for all FSP

Discussion

Initial loading for midfoot striking is significantly higher than forefoot striking but significantly lower than rear-foot striking.

- Combining midfoot and forefoot strike running steps *not* appropriate when analyzing initial loading parameters.
- Forefoot striking may be more protective from some running-related overuse injuries than midfoot strike running.
- Midfoot striking may decrease injury risk relative to a rearfoot strike pattern.

Runners habituated to partial minimal shoes land harder in true minimal footwear than those habituated to true minimal footwear, even when using the same foot strike pattern.

- Habituating to increased cushioning increases reliance on the cushioning. Implications for:
  - Validity of research evaluating footwear using subjects new to the footwear style.
  - Injury risk increases as cushioning degrades over the lifetime of the shoe.
- Aligns with previous research showing increased cushioning increases initial loading, even with same foot strike pattern[4,5] [[4]subjects new to footwear style]

Conclusion

Results of this study suggest that 1) midfoot strike and forefoot strike impacts are different from each other and that 2) habituated footwear matters when analyzing impacts in runners.

References

1. Lieberman DE et al. Nature 463, 531-535.
2. Kulmala JP, et al. MSSE 45, 2306-2313.
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