EFFECT OF RUNNING SHOES ON BIOMECHANICS AND SUBJECT VARIABILITY

Azevedo L.B, Schwellnus M.P, Lambert M, Vaughan C.L
University of Cape Town

INTRODUCTION

It has been shown that shoes (Clarke et al, 1983; Nigg et al, 1987) or surfaces {Dixon et al, 2000} with different mechanical properties do not affect vertical impact forces peak (VIF) but could affect vertical loading rate (VLR) (Clarke et al, 1983),. The reason for this is not clear, but it could be due to kinematic adjustments that occur immediately before or at the very beginning of the contact phase (, Ferris et al,1999, Dixon et al, 2000, Hardin et al, 2004). Inter - subject variability also appears to have a significant effect on the kinematic variables, which may be related to sensory feedback from the foot and lower limb (Kurz et al, 2003, Dufek et al, 1991). However, there is a need to understand how knee and ankle dynamic variables are affected by different shoes. Therefore, the aim of this study was to investigate the effect of four different commercially available running shoes on lower extremity kinetics, kinematics, knee and ankle dynamic variables during running. Furthermore, the inter-subject variability between different biomechanic variables was studied.

METHODS

Fifteen healthy non-injured male runners (N=15) were recruited from a University population to participate in the study (mean age: 29.9 ± 7.0 years; mean body mass: 72.1 ± 10.3 kg; mean height: 1.71 ± 0.04 cm). Four commercially available running shoes (1, 2, 3, 4) classified as cushioned shoes from different brands were selected. The running shoe characteristics are described in Table 1. Fifteen retro-reflective markers from the modified Helen Hayes marker set (Vaughan et al, 1999). and six-camera motion analysis system (Oxford Metrics Vicon System 370 Version 2.5, Oxford Metrics Ltd, Oxford, United Kingdom) were used to collect kinematic data at 120 Hz. Ground reaction force data were collected with an Advanced Mechanical Technology, Inc. (AMTI ® Newton, MA, USA) force plate (1000 Hz). Ten valid running trials over a distance of ten meters were completed in each running shoe by the subject. The mean kinetic, kinematic and inverse dynamics variables for each running shoe condition and the coefficient of variance (calculated as standard deviation/mean * 100) of each variable were compared with the repeated measures ANOVA at the level of significance of $p<0.05$. Significant relationships between the means were further explored with Tukey post hoc analysis test.

RESULTS

There were no significant differences between different shoes on temporal distances parameters (running speed, stride length, cadence, contact time and vertical sacrum marker displacement). Table 2 shows that vertical impact force at 25 ms (VIF25), vertical loading rate at 25 ms (VLR25) and time to vertical impact force peak (TVIF) were significantly higher in shoe 4 than shoes 1, 2 and 3. However, VIF, VLR and vertical propulsive force (VPF) were similar between shoes. Shoe 2 was associated with a higher horizontal breaking force than the other shoes. There was a higher knee angle on initial contact (Kic) with Shoe 4 compared to Shoes 1 and 2 (Table 3). There was an increase in ankle dorsiflexion at terminal swing phase (Asw) in Shoe 2 compared to Shoes 1 and 4 as well as on initial contact in Shoe 2 (Aic) compared to Shoe 4.

Table 1: Running shoes characteristics

	Cushioning system	Material midsole	Weight (g)	Flare angle (°)	Shore
Shoe 1	cushioning column	EVA	409	5	40
Shoe 2	cushioning column	PU	425	3	70
Shoe 3	Single midsole unit	EVA	428	8	45
Shoe 4	Single midsole unit	EVA	225	8	50

Table 2: Ground reaction force on different running shoes

	Shoe 1	Shoe 2	Shoe 3	Shoe 4
HBF (BW)	0.25 ± 0.04	0.29 ± 0.06*	0.26 ± 0.05	0.26 ± 0.06
HPF (BW)	0.16 ± 0.04	0.15 ± 0.05	0.16 ± 0.03	0.18 ± 0.03
VIF25 (BW)	0.66 ± 0.26	0.77 ± 0.20	0.73 ± 0.23	0.93 ± 0.31 †
VLR25 (BW/s)	26.6 ± 10.2	30.7 ± 8.2	29.2 ±9.2	37.3 ±12.5 †
VIF (BW)	1.61 ± 0.32	1.56 ± 0.48	1.67 ± 0.28	1.46 ± 0.31
VLR (BW/s)	32.8 ± 8.6	31.5 ± 11.4	33.1 ± 7.1	34.1 ± 10.6
TVIF (ms)	49.8 ± 5.4	50.9 ± 4.3	50.3 ± 4.9	44.5 ± 7.0 †
VPF (BW)	2.45 ± 0.27	2.37 ± 0.35	2.47 ± 0.26	2.46 ± 0.26

* Significant differences between Shoe 2 and Shoes 1, 3 and 4 ($P< 0.01$)
† Significant differences between Shoe 4 and Shoes 1, 2 and 3 ($P< 0.01$)

Table 3: Knee and ankle joint kinematics on different running shoes

	Shoe 1	Shoe 2	Shoe 3	Shoe 4
KswF (°)	86.2 ± 2.8	84.8 ± 4.3	85.4 ± 5.0	85.0 ± 4.9
KswE (°)	17.9 ± 7.8	17.5 ± 6.9	18.7 ± 7.7	19.3 ± 8.6
Kic (°)	19.9 ± 6.9	19.4 ± 6.2	21.1 ± 7.0	21.6 ± 7.9*
Kst (°)	49.1 ± 6.8	49.4 ± 6.0	48.6 ± 6.4	48.7 ± 6.8
Asw (°)	-14.0 ±6.4	-16.9 ± 5.7 †	-14.7 ± 6.1	-13.6 ± 6.9
Aic (°)	-14.4 ± 6.3	-17.0 ± 5.1 ††	-15.0 ± 6.1	-14.0 ± 6.7
Ast (°)	-20.7 ± 3.9	-22.7 ± 4.5	-23.5 ± 3.4	-22.0 ± 3.8
Δγpro (°)	24.7 ± 6.1	24.0 ± 6.6	22.9 ± 5.2	23.5 ± 4.2

* Significant differences between Shoe 4 and Shoes 1 and 2 ($P< 0.01$)
† Significant differences between Shoe 2 and Shoes 1 and 4 ($P< 0.01$)
†† Significant differences between Shoe 2 and Shoe 4 ($P< 0.05$)

However, there was no significant difference in ankle angle at stance phase (Ast), range of foot eversion (Δγpro), knee angle at stance phase (Kst) and knee angle flexion (KswF) and extension (KswE) at swing phase. Ankle power generation was significantly higher in Shoe 4 than Shoe 3 (Shoe 3: 6.70±1.75 W/kg vs. Shoe 4: 7.91±2.15 W/kg; $p<0.05$) and ankle power absorption was different between running shoes ($p<0.05$). However, there was insufficient statistical power to identify the specific differences with Tukey test. Concentric and eccentric work were similar between running shoe conditions. Analyzing the coefficient of variation (CV) from each variable we found a significantly higher CV in VIF 25 ms compared with VPF (Figure 1). A higher CV was also found in KswE compared with Kic and Kst; and higher CV on Kic than Kst (Figure 2). The CV of ankle angle was lower in Ast than Asw or Aic.

DISCUSSION

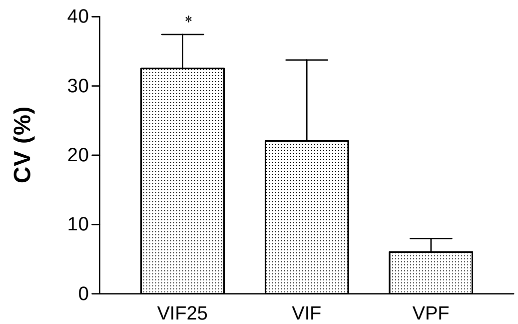
Vertical impact forces and vertical loading rate were similar despite different midsole hardness or shoe construction, confirming results of previous studies in the literature (Nigg, et al, 1987, Nigg et al, 1988). However, the impact force and loading rate were affected at the 25 ms of contact phase. Kinematic adjustments such as the higher knee flexion angle at heel strike may explain why impact forces are able to adjust at the peak level. The results of this study show that it was not the shoe with the harder heel midsole (Shoe 2) (Table 1) which resulted in a higher impact force at 25 ms, but the shoe with the lowest weight (Shoe 4). Another interesting finding was that Shoe 2 promotes a higher HBF and increased ankle dorsiflexion at terminal swing phase and heel strike. This may be due to the lower flare angle in Shoe 2 than shoes 1, 3 and 4 (Table 1). Concerning the dynamics of the ankle and knee, the higher power generation in Shoe 4 compared with Shoe 3 could be related to a greater angular velocity and increased plantarflexion in Shoe 4 than Shoe 3. A novel finding from this study was that inter-subject variability as measured by the coefficient of variation was higher at initial contact than at midstance for the ground reaction force variables (Figure 2). Similar results were found in the knee and ankle angle where there was greater variability at the terminal swing phase than heel strike and at midstance phase (Figure 3).

CONCLUSION

According to our results, it appears that the body tends to adjust the impact force very early in the contact phase. This force regulation can be attributed to kinematic adjustments at heel contact. Characteristics such as shoe weight and flare angle affect kinematics in the sagittal plane. There is greater subject variability in kinetic variables very early during the contact phase (25 ms) than in midstance. Similarly, there is greater variability in the kinematic variables before contact and heel strike than in midstance. Therefore, we can conclude that different running shoes affect running kinetics and kinematics at or before heel strike but not at midstance.

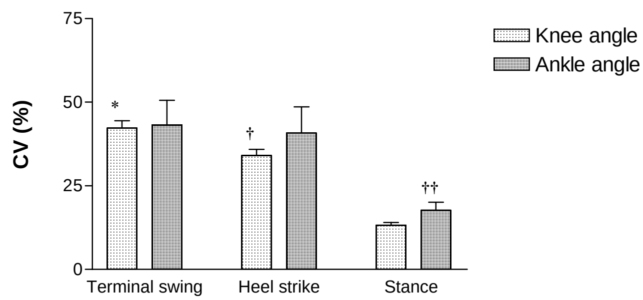
Acknowledgment to São Paulo Alpargatas

Figure 1: Coefficient of variation at vertical impact force at 250 ms, vertical impact force peak and vertical propulsive force.



* Significant difference between VIF 25 and VPF (P <0.01).

Figure 2: Coefficient of variation at terminal swing phase, heel strike and stance phase.



* Knee angle significantly different from heel-strike and stance phase (P<0.01).
† Knee angle significantly different from stance phase (P<0.01).
†† Ankle angle significantly different from terminal swing and heel strike (P<0.01).

REFERENCES

Clarke,TE, et al, 1983: Int.J.Sports Med., v. 4, p. 247-251.
Dixon,SJ, et al, 2000: Med.Sci.Sports Exerc., v. 32, p. 1919-1926.
Dufek,JS, et al, 1991: Med.Sci.Sports Exerc., v. 23, p. 1062-1067.
Ferris,DP, et al 1999: J.Biomech., v. 32, p. 787-794.
Hardin,EC, et al, 2004,: Med.Sci.Sports Exerc., v. 36, p. 838-844.
Kurz,MJ, N Stergiou, 2003: Gait.Posture., v. 17, p. 132-135.
Nigg,BM et al, 1987: J.Biomech., v. 20, p. 951-959.
Nigg,BM et al, 1988: Am.J.Sports Med., v. 16, p. 70-76.
Vaughan et al, 1999: Dynamics of Human Gait. Kiboho Publishers.