ARCH-TYPE AND SHOE INTERACTIONS DURING RUNNING

S. M. FULLER AND J. HAMILL

BIOMECHANICS LABORATORY DEPARTMENT OF EXERCISE SCIENCE UNIVERSITY OF MASSACHUSETTS AMHERST

INTRODUCTION

The anatomical structure of the foot and the structure of the running shoe are two factors that have been suggested to influence the lower extremity joint actions during running. Foot structures dealing with the longitudinal arches of the foot have been implicated in running injuries. These arch types range from pes planus, flat arched foot, to pes caws, high arched foot. In the pes planus foot, there is a large weight-bearing surface because of the fallen arch. A flat arched foot is very flexible and is usually hypermobile. This type of foot structure is less efficient in propulsion and, to compensate, the subtalar joint excessively pronates (Franco, 1987). In the pes cavus foot, weight-bearing is distributed along the lateral border of the foot and across the first, second and fifth metatarsal heads. High arched feet are considered a rigid foot structure resulting in an inability to absorb shock (Tiberio, 1987). The pes caws foot, therefore, excessively inverts at the subtalar joint and the forefoot supinates.

The structure of the running shoe can affect motion at the subtalar joint (Cavanagh, 1980). Clarke et al. (1983) reported that both the maximum pronation angle and total rearfoot motion were significantly increased with the use of a soft midsole shoe when compared to a hard midsole shoe. Hamill et al. (1992) reported that a change in the construction of the midsole of a running shoe can affect the timing between the subtalar and knee joints. They suggested that the joint actions of the lower extremity must occur simultaneously or injury may result.

Previous research suggests that anatomically dysfunctional feet and running shoe construction each independently can cause a disruption in the lower extremity. The purpose of this study was, therefore, to examine the interaction of foot arch-type and running shoe midsole hardness on lower extremity mechanics.

METHODOLOGY

Eighteen healthy, male, recreational runners served as subjects. The subjects were divided into three groups based on foot pressure data collected using a Tekscan pressure mat. The ratio of the midfoot force to the total force categorized runners as high-arched (HA), normal arched (NA), or flat-arched (FA).

The experimental set-up consisted of three 200 Hz high speed video cameras and recorders positioned so that all markers were visible in at least two cameras; a force platform; and a photoelectric timing system to ensure constant running speed. The shoes used in the study were expressly constructed for this study and were identical except for the midsole density. The hard midsole shoe had a durometer of 70 (shore A scale) and the soft midsole shoe a durometer of 25 (shore A).

Each subject underwent a lower extremity evaluation during which time anthropometric measures were taken. Static and dynamic foot pressures were then recorded. Retro-reflective markers were placed on each subject according to a protocol described by Vaughan et al.(1992). Each subject then completed 15 successful trials in each of two running shoes at a locomotor speed of 3.5 m/s.

The video data were digitized using a Motion Analysis VP110 processor and a minicomputer. A direct linear transformation was used to construct the 3-D coordinates during the support phase of each running trial. Angles were calculated using the procedure of Vaughan et al. (1992) and parameters describing the percent time to the maxima of the hip, knee, and ankle angles were determined. The ground reaction force data were scaled to each subject's body mass and parameters describing key events on each of the GRF components were calculated. The arch-type data were evaluated using a one-way ANOVA. The 15-trial means of each of the kinematic and GRF parameters for each subject/condition were statistically analyzed using a two-way (Shoe X Arch-type) repeated measures ANOVA.

RESULTS

The mean values of the kinematic timing parameters and the GRF parameters are presented in Tables 1 and 2 respectively. A significant difference was found between arch types with the mean values of the ratios 0.125, 0.160, and 0.257 for the HA, NA, and FA groups respectively. No significant differences were found between shoe conditions or between arch types for any of the kinematic timing parameters ($p < 0.05$). However, significant interactions were observed between shoe conditions and arch groups for total support time and for the percent time to maximum femoral rotation. Significant differences were found between shoe conditions for five GRF parameters ($p < 0.05$, Table 2). No significant differences were found between arch types for any of the GRF parameters ($p < 0.05$).

Table 1 - Mean values for kinematic timing parameters.

	Soft Midsole Shoe			Hard Midsole Shoe		
	FA	NA	HA	FA	NA	HA
time-rearfoot angle	47.54	41.69	34.95	40.79	46.26	35.96
time-knee flex. angle	46.49	47.76	37.81	42.51	46.91	47.91
time-int. tibial rot. angle	24.28	23.52	34.39	37.36	41.90	28.63
time-ext. femoral rot. angle	24.00	44.78	35.50	42.53	42.86	34.81
total stance time (s)	0.20	0.21	0.22	0.21	0.21	0.21

The values for all parameters except stance time reflect the percent time to the maxima of the stated angle.

Table 2 - Mean values for ground reaction force parameters.

Soft Midsole Shoe			Hard Midsole Shoe			
	FA	NA	HA	FA	NA	HA
Vertical						
% time to 1st max. force	15.01	14.69	14.56	14.97	13.73	14.19
1st max. force	16.58	13.23	11.42	17.06	13.84	**11.79***
% time to 2nd. max force	43.65	43.44	45.05	43.49	43.16	44.84
2nd max. force	23.15	19.04	15.88	22.97	18.84	**15.56***
average force	13.74	11.71	9.70	13.84	11.79	9.62
total impulse	3.16	2.67	2.12	3.14	2.70	2.12
Anterio-posterior						
%time to max.braking force	25.51	25.61	36.34	25.69	25.25	26.19
max. braking force	-3.50	-2.89	-2.10	-3.56	-2.95	-2.17
% time to transition	51.91	52.25	50.58	52.62	52.49	50.74
%time to max. prop. force	76.27	77.49	76.74	77.04	78.55	**76.95***
max. propelling force	2.71	2.34	2.03	2.75	2.34	2.04
Medio-lateral						
force excursions (0-30% of support)	2.12	1.92	1.67	2.01	2.32	**1.86***
force excursions (0-100% of support)	3.63	3.63	3.12	3.52	3.90	**3.45***

Force - N/kg; time - percent to support; impulse - N.s/kg

*Significant differences ($p < 0.05$) between shoes but not among arch groups

DISCUSSION

The purpose of this study was to examine the interaction of foot arch-type and running shoe midsole hardness on lower extremity mechanics. Arch-type was evaluated using both static and dynamic techniques. The static technique was ultimately used because the standard deviations among trials were less than for the dynamic trials. Although there were significant differences among the arch-types, there appeared to be few distinctions in the mechanics of the lower extremity during running that would differentiate these individuals.

Hamill et al. (1992) suggested that the mis-timing of lower extremity joint actions was a probable mechanism for injury. It was felt that FA individuals, because of their propensity for hyper-pronation of the subtalar joint, would pronate more that the other arch-types and thus the mis-timing would be apparent. That is, maximum knee flexion, maximum internal tibial rotation, and maximum external femoral rotation would occur earlier in the stance phase than maximum subtalar pronation. This effect would theoretically be exacerbated by the soft midsole shoe because it would accentuate pronation. On the other hand, the HA individuals generally pronate less than the NA or FA groups and mis-timing would be apparent in that case also. That is, maximum knee flexion, maximum internal tibial rotation, and maximum external femoral rotation would occur later in the stance phase than maximum subtalar pronation. These effects would theoretically more dramatic in the firm midsole shoe because this shoe would constrain pronation.

The results of this study do not suggest a clear pattern. Only two kinematic parameters resulted in significant shoearch-type interactions; total stance time and the percent time to maximum femoral external rotation (MFIR). The HA group exhibited the same values for MFIR in both shoes while the NA and FA groups were clearly affected by the shoes. While not statistically significant trends in the data generally revealed that the timing of the joint actions for the HA group appeared most optimal in the soft midsole shoe and most optimal for the FA and NA groups in the hard midsole shoe.

In terms of the GRF parameters, there were five significant parameters but all differences were between shoes and not among arch-types. The lack of significant differences among arch-types and the lack of interactions suggest that ground reaction forces are not sensitive to variations in arch-types.

CONCLUSIONS

Based on the results of this study, the following conclusions are warranted:

1) some disruption of the timing of lower extremity joint actions occurs depending on the specific combination of arch height and shoe midsole durometer.

2) for individuals with hypermobile feet (FA), a hard midsole shoe may be beneficial in preventing lower extremity injury.

3) for individuals with rigid feet (HA), a soft midsole shoe may be beneficial in preventing lower extremity injury.

REFERENCES

Cavanagh, P. R. The Running Shoe Book. Mountain View, CA: World Publications, pp. 52-95, 1980

Clarke. T. E. et al. The effects of heel height, flare, and midsole softness upon rearfoot control in running. Med Sci Sports Exerc 15:376-381, 1983

Franco, A .H. Pes cavus and pes planus - analyses and treatment. Phys. Ther. 67:688-694, 1987

Hamill, J. et al. Timing of lower extremity joint actions during treadmill running. Med Sci Sports Exerc 24:807-813, 1992

Tiberio, D. The effect of excessive subtalar pronation on patello-femoral mechanics: a theoretical model. J Orth Sports Phys Ther 9:106-164, 1987

Vaughan, C. L. et al. Dynamics of Human Gait. Champaign, IL: Human Kinetics Publications, pp. 15-43, 1992