

American Journal of Sports Medicine

<http://ajs.sagepub.com>

Interaction of Arch Type and Footwear on Running Mechanics

Robert J. Butler, Irene S. Davis and Joseph Hamill

Am. J. Sports Med. 2006; 34; 1998 originally published online Aug 10, 2006;

DOI: 10.1177/0363546506290401

The online version of this article can be found at:
<http://ajs.sagepub.com/cgi/content/abstract/34/12/1998>

Published by:

 SAGE Publications

<http://www.sagepublications.com>

On behalf of:



[American Orthopaedic Society for Sports Medicine](#)

Additional services and information for *American Journal of Sports Medicine* can be found at:

Email Alerts: <http://ajs.sagepub.com/cgi/alerts>

Subscriptions: <http://ajs.sagepub.com/subscriptions>

Reprints: <http://www.sagepub.com/journalsReprints.nav>

Permissions: <http://www.sagepub.com/journalsPermissions.nav>

Citations (this article cites 24 articles hosted on the
SAGE Journals Online and HighWire Press platforms):
<http://ajs.sagepub.com/cgi/content/abstract/34/12/1998#BIBL>

Interaction of Arch Type and Footwear on Running Mechanics

Robert J. Butler,^{*†} PhD, Irene S. Davis,^{‡§} PT, PhD, and Joseph Hamill,^{||} PhD
From the [†]Department of Exercise and Sport Science, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, [‡]Department of Physical Therapy, University of Delaware, Newark, Delaware, [§]Drayer Physical Therapy Institute, Hummelstown, Pennsylvania, and ^{||}Department of Exercise Science, University of Massachusetts, Amherst, Massachusetts

Background: Running shoes are designed to accommodate various arch types to reduce the risk of lower extremity injuries sustained during running. Yet little is known about the biomechanical changes of running in the recommended footwear that may allow for a reduction in injuries.

Purpose: To evaluate the effects of motion control and cushion trainer shoes on running mechanics in low- and high-arched runners.

Study Design: Controlled laboratory study.

Methods: Twenty high-arched and 20 low-arched recreational runners (>10 miles per week) were recruited for the study. Three-dimensional kinematic and kinetics were collected as subjects ran at $3.5 \text{ ms}^{-1} \pm 5\%$ along a 25-m runway. The motion control shoe evaluated was the New Balance 1122, and the cushioning shoe evaluated was the New Balance 1022. Repeated-measures analyses of variance were used to determine if low- and high-arched runners responded differently to motion control and cushion trainer shoes.

Results: A significant interaction was observed in the instantaneous loading rate such that the low-arched runners had a lower instantaneous loading rate in the motion control condition, and the high-arched runners had a lower instantaneous loading rate in the cushion trainer condition. Significant main effects for shoe were observed for peak positive tibial acceleration, peak-to-peak tibial acceleration, mean loading rate, peak eversion, and eversion excursion.

Conclusion: These results suggest that motion control shoes control rearfoot motion better than do cushion trainer shoes. In addition, cushion trainer shoes attenuate shock better than motion control shoes do. However, with the exception of instantaneous loading rate, these benefits do not differ between arch type.

Clinical Relevance: Running footwear recommendations should be based on an individual's running mechanics. If a mechanical analysis is not available, footwear recommendations can be based empirically on the individual's arch type.

Keywords: high arch; low arch; shoes; midsole

The *Healthy People 2010* initiative encourages Americans to engage in regular exercise throughout their lifetimes. Running is a popular form of exercise that has observed a drastic increase in participation recently. Unfortunately, with this increase in popularity, running injuries have become more common.²⁹

The only equipment a runner has to protect against overuse injuries sustained during running is a pair of shoes. However, there are many types of shoes from which to

choose. Choosing the appropriate shoe may be more crucial for high-arched (HA) and low-arched (LA) individuals because these individuals have been reported to have an increased incidence of injuries compared with individuals with average arch structure.¹⁶ Running injuries are often related to either excessive motion or excessive shock.^{15,22} These injuries have been attributed, in part, to the foot type of the individual. According to Williams et al,³² runners with LA feet are more likely to sustain soft tissue injuries, such as posterior tibialis tendinitis, whereas HA runners are more likely to sustain bony injuries, such as stress fractures.¹³ These differences in injury risks may be related, in part, to increased eversion excursion observed in LA runners and higher loading rates experienced by HA runners.³³ It has been suggested that foot orthoses can reduce the risk of sustaining overuse injuries.^{7,8,26} Similarly, it may be that running in the appropriate shoe may be able to alter the

*Address correspondence to Robert J. Butler, PhD, University of Evansville, Department of Physical Therapy, 1800 Lincoln Ave, Evansville, IN 47722 (e-mail: robertjbutler@lycos.com).

No potential conflict of interest declared.

mechanics that are associated with injury in such a way that the risk of injury would be reduced.

Motion control (MC) and cushioning training (CT) running shoes are designed to accommodate LA and HA feet, respectively, with the aim of reducing injuries. A study by Knapik et al¹⁸ examined the influence of matching arch height with shoe type on injuries. Injuries were recorded at the physical therapy clinic for a period of 6 months before and 6 months after the shoe recommendation program. These authors reported a 50% reduction in lower extremity and back injuries after the implementation of the shoe recommendation program. Although these results are impressive, the mechanisms behind the apparent injury reduction were not explored and thus remain unknown.

It is possible that injuries were reduced because of the influence of the footwear on lower extremity mechanics. Several studies have been conducted comparing rearfoot mechanics when running in shoes with different midsole stiffness values. These studies have reported that stiffer midsoles reduce peak eversion and eversion excursion.^{6,14} Midsole geometry can also influence rearfoot mechanics. Perry and LaFortune²⁴ reported that rearfoot eversion was increased by incorporating a valgus wedge into the midsole and was decreased when adding a varus wedge. They also noted that the varus wedge increased tibial shock, impact peak, and vertical loading rates compared with both the valgus wedge and neutral insole condition. Thus, although MC shoes (which typically incorporate stiffer midsoles and a varus wedge) reduce rearfoot motion, they may also increase lower extremity shock and ground reaction forces compared with a CT shoe (which typically incorporate more compliant midsoles).

Changing midsole hardness can also decrease the magnitude of the lower extremity shock that one experiences. However, results of studies on the effect of midsole durometer on shock have been contradictory. As expected, bench-top impact studies have revealed that both force and shock decrease with decreasing midsole durometer.^{12,23} Conversely, some studies have suggested that the vertical impact peak actually increases when subjects run in shoes with softer midsole materials.^{3,5,27} Therefore, it appears that there is a runner-footwear interaction that is not apparent in the bench-top studies. The increase in impact peak on the softer surface suggests that runners increase their lower extremity stiffness when running on a compliant surface. This adaptation is further supported by Ferris et al,¹⁰ who reported that runners adjust their lower extremity stiffness when landing on a new surface of a known stiffness. Runners increased their lower extremity stiffness when landing on a soft surface and decreased their lower extremity stiffness when landing on a hard surface.^{16,17} Thus, it appears that runners may adjust their landing in response to the type of surface on which they are running. No studies to date have examined whether runners adjust their stiffness in response to different footwear.

In summary, it has been reported that HA and LA runners exhibit different running mechanics. In addition, it has been reported that running shoe characteristics influence rearfoot mechanics and impact loads. It has been previously reported that running in the correct shoe for arch type can

reduce the number of injuries that runners sustain, although the reasons for these reductions are not clear.¹⁸ Therefore, the purpose of this study was to examine the interaction of arch type and footwear on rearfoot mechanics and loading variables. It was hypothesized that rearfoot and tibial motion would be decreased in the MC shoe compared with the CT shoe and that the effect would be greater in the LA than in the HA individuals. In addition, it was hypothesized that tibial shock and loading variables would be reduced in the CT shoe compared with the MC shoe and that the effect would be greater in the HA individuals compared with the LA individuals. Finally, it was hypothesized that lower extremity stiffness and knee joint stiffness would be increased in the CT compared with the MC shoe, regardless of foot type.

METHODS

Based on an a priori sample size estimate ($\alpha = .05$, $\beta = .20$) using variability from De Wit et al⁶ and an expected 15% difference between groups, 12 to 16 subjects per group were needed to adequately power the study.⁴ Twenty HA (11 women, 9 men) and 20 LA (10 men, 10 women) recreational runners were therefore recruited for the study. Potential subjects were recruited from the local community. All subjects were between the ages of 18 and 40 years and currently running at least 10 miles per week. Subjects were excluded if they had a history of any cardiovascular problems or any condition that might influence their gait patterns. Subjects who met the study criteria were invited to the laboratory for an arch height screening.

The Arch Height Index (AHI) Measurement System (Figure 1) was used to measure the AHI according to Williams and McClay.³⁰ This device was determined to be highly reliable in a previous research study.² Both feet were measured while the subject was seated and then in bilateral stance. Measurements of foot length, truncated foot length (from heel to first metatarsophalangeal joint), and height of the dorsum of the foot at half-resting total foot length (Figure 2) were taken for each subject. Although not a primary screening measure, AHI stiffness (AHI/kg) was also calculated on the subjects by dividing the change in AHI between sitting and standing by the change in loading (approximated as 10% body weight during sitting and 50% body weight during bilateral stance). Subjects with AHI values that were 1.5 SD above (HA) and 1.5 SD below (LA) a previously determined population ($N = 100$) AHI mean value were included in the study.² All included subjects reviewed and signed an informed consent that was approved by the institutional review board.

Qualified subjects then returned to the laboratory for the motion analysis. Retroreflective markers were placed on the greater trochanters bilaterally, on the medial and lateral condyles of the knee, on the medial and lateral malleoli of the ankle, at the base of the first and fifth metatarsal, and on the tip of the shoe on the limb of interest (Figure 3). These anatomical markers were used to determine the local coordinate system for the foot, shank, thigh, and pelvis. To monitor pelvic motion, individual tracking markers were

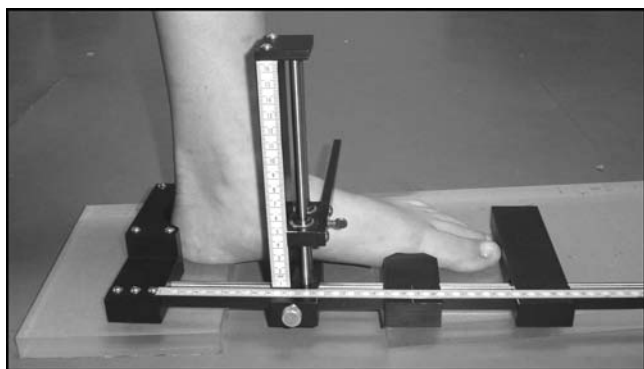


Figure 1. Arch Height Index Measurement System device being used on a potential subject.

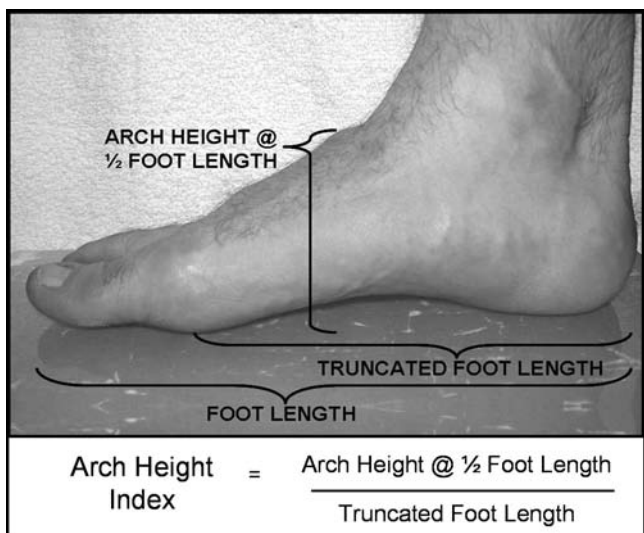


Figure 2. Arch height index measurements and formula.

attached directly to the skin by using Elastikon tape (Johnson & Johnson, Arlington, Tex) at the iliac crest, L5-S1 junction, and anterior superior iliac spine. Four tracking markers were rigidly attached to a thermoplastic shell that was placed on the thigh and shank to track their motion. Calcaneal motion was monitored by placing tracking markers directly on the skin over the calcaneus. The markers were placed along a line bisecting the posterior aspect of the calcaneus. The calcaneal markers were placed on stems that protruded through windows cut in the heel counter of the shoes (Figure 3 insert). This method attempts to obtain a more accurate assessment of rearfoot motion during stance because it has previously been reported that markers placed on the shoe overestimate rearfoot motion.²⁸ Pilot work was done to determine the optimal size of the windows that allowed maximal marker visibility with minimal heel counter degradation. The windows in the heel counter of the experimental shoes resulted in approximately a 10% reduction in heel counter stability as measured by an Instron

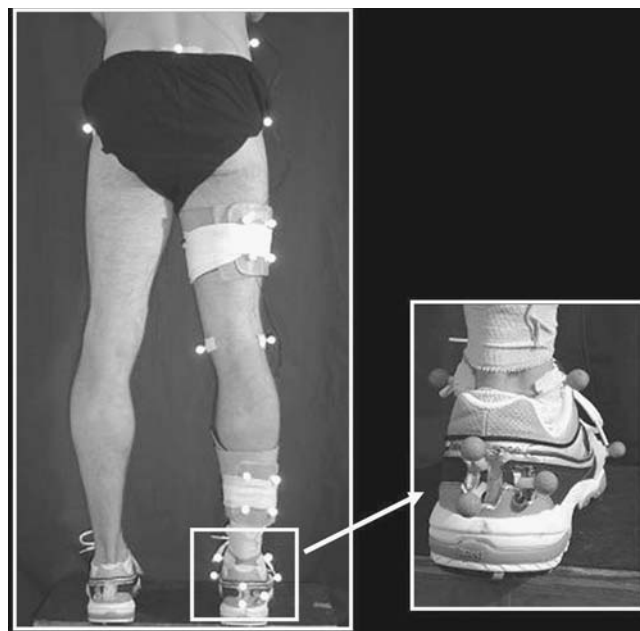


Figure 3. Marker set used during data collection. Picture on right displays location of rearfoot markers placed directly on the calcaneus.

Testing Device (Instron, Canton, Mass). After a standing calibration was taken, all anatomical markers were removed. The acceptability of the between- and within-day reliability for this marker set has previously been reported.⁹

Overground data were collected as the subject ran along a 25-m runway. Marker coordinates of the tracking markers were recorded using a 6-camera motion analysis system (VICON, Oxford Metrics, London, England) operating at 120 Hz. A force plate (Bertec, Worthington, Ohio), located in the center of the calibrated volume, was used to collect ground reaction forces during stance of each trial. A uniaxial accelerometer (PCB Piezotronics, Depew, NY) placed on the distal, anteromedial aspect of the tibia, in alignment with the long axis of the tibia, was used to record tibial shock. The accelerometer, encased in lightweight aluminum, was adhered to the skin with an overwrap of Elastikon tape fastened around the circumference of the tibia. The total mass of the accelerometer and casing was 2.73 g. This method is similar to that which has been used in previous studies by Mercer et al.^{20,21} Both ground reaction force and accelerometry data were sampled at 1080 Hz. All subjects ran at $3.57 \text{ ms}^{-1} \pm 5\%$ along a 25-m runway. Running speed was determined by wall-mounted photocells and a timer. The photocells were a total of 2.33 m apart and equidistant from the center of the force platform. Only trials in which force plate contact was made with the correct foot, at the correct speed, without visible targeting were accepted.

All subjects ran in both shoe conditions. The first shoe condition was randomly assigned. The MC shoe tested was the New Balance 1122MC, and the CT shoe was the New Balance 1022NC (New Balance Athletic Shoes, Inc, Boston, Mass) (Figure 4). The MC shoe is constructed using a straight cardboard last design with a rearfoot-to-midfoot



Figure 4. Medial and plantar views of the 2 shoes used in the study. Left, cushion trainer shoe. Right, motion control shoe.

dual-density medial post. To add to the MC properties of the shoe, a thermoplastic Rollbar is placed in the rearfoot portion of the midsole. The MC shoe has Abzorb inserts in the forefoot and rearfoot to provide some shock attenuation. The CT shoe incorporates a semicurved last with a single-density rearfoot foam and Abzorb inserts in the forefoot and rearfoot. Also, the upper is attached directly to the midsole without using cardboard to increase the flexibility of the shoe. Both shoes retail for more than \$100.

The 3D marker coordinates were low-pass filtered using a second-order Butterworth filter with a cutoff frequency of 8 Hz. Visual 3D software (C-Motion, Rockville, Md) was used to calculate kinematic and kinetic variables of interest. The ground reaction force data were low-pass filtered using a 50-Hz Butterworth filter. A 10-N vertical ground reaction force threshold was used to determine heel strike and toe-off. All kinematic data were scaled to 100% of stance. Five trials were averaged to develop a representative set of trials for each subject in each condition.

Based on the reported function of these 2 types of shoes (rearfoot control in the MC and shock attenuation in the CT), rearfoot motion and impact loading variables were assessed. Rearfoot motion variables included peak eversion, eversion excursion, peak tibial internal rotation, and tibial internal rotation excursion. The impact loading variables were derived from ground reaction force and tibial accelerometry. Impact peak was the first peak in the vertical ground reaction force data, usually occurring within the first 50 milliseconds of stance. Mean vertical loading rate was calculated as the slope of the vertical ground reaction force over the interval from 20% to 80% of the initial peak. Instantaneous vertical loading rate, using the central difference method, was examined as the maximum instantaneous slope between heel strike and impact peak. Tibial shock was evaluated by calculating the peak positive tibial acceleration and the difference between the peak positive and peak negative acceleration (peak-to-peak tibial acceleration) from the accelerometry trace. Rearfoot variables were chosen for their association with injury mechanisms related to excessive eversion. The tibial motion variables were chosen for their association with injury

mechanisms at the knee. The impact variables were chosen for their association with bony injuries.^{22,25}

The global measure of lower extremity stiffness during the loading phase was calculated using the mass-spring model described by McMahon and Cheng.¹⁹ In addition, knee flexion joint stiffness was examined. Knee flexion joint stiffness was calculated as the slope of the most linear portion of the joint position and joint moment trace from heel strike to peak knee flexion (Figure 5). The most linear portion of this curve was identified as the region between the minimal knee flexion moment and maximal knee flexion joint moment during the first half of stance.

A 2-factor (shoe type \times arch height) mixed-design analysis of variance was used to test each hypothesis. Significant differences for all statistical analyses were determined using $\alpha = .05$.

RESULTS

The mean AHI values were 0.273 (2.4 SD below the population mean) for the LA runners and 0.390 (1.8 SD above the population mean) for the HA runners, suggesting clearly delineated arch structures. In addition, HA runners had arches that were twice as stiff as those of the LA runners (Tables 1 and 2). All other subject characteristics (height, age, mass, miles run per week) were similar between the 2 groups.

A significant interaction was noted for instantaneous loading rate (Figure 6). The HA runners had a reduced instantaneous loading rate in the CT, as expected; on the other hand, LA runners had an increased instantaneous loading rate in the CT. No other interactions were observed.

Significant main effects for the shoe condition were found for several variables (Figure 7). Peak eversion and eversion excursion were decreased in the MC compared with the CT. Peak eversion was reduced by 11% and eversion excursion reduced by 6% in the MC compared with the CT.

In terms of loading, both peak positive tibial acceleration and peak-to-peak tibial acceleration were reduced in the

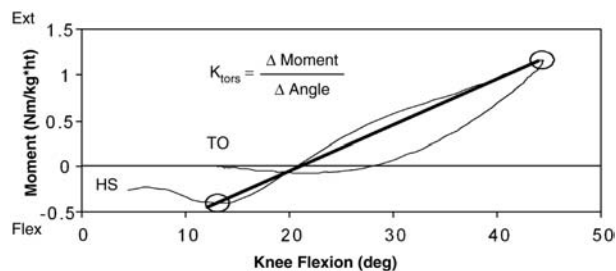


Figure 5. Joint stiffness calculation for the sagittal plane at the knee.

TABLE 1
Descriptive Statistics for High- and Low-Arched Subjects

	High Arch		Low Arch	
	Mean	SD	Mean	SD
Age, y	22.3	4.4	22.8	4.7
Height, m	1.71	0.07	1.73	0.10
Mass, kg	70.83	10.08	66.78	7.98
Arch height index	0.390	0.015	0.291	0.018
Arch stiffness, kg/arch height index	1993.84	1112.07	788.03	406.98
Mean miles per week run	19	13	21	9

TABLE 2
Means and SDs for All of the Variables of Interest^a

Variable/Footwear	High Arch		Low Arch		P		
	Mean	SD	Mean	SD	Interaction	Footwear	Arch Type
Peak eversion, deg							
MC	7.4	3.4	6.3	2.7	.33	.03	.55
CT	8.0	3.0	7.9	3.4			
Eversion excursion, deg							
MC	9.7	2.6	12.6	2.7	.11	.04	.00
CT	9.8	2.9	13.7	2.7			
Peak tibial internal rotation, deg							
MC	9.1	6.7	8.7	3.8	.44	.62	.95
CT	8.3	4.9	8.9	3.5			
Tibial internal rotation excursion, deg							
MC	8.9	5.0	8.5	3.7	.84	.12	.71
CT	9.7	3.3	9.2	2.6			
Impact peak, bw							
MC	1.72	0.30	1.67	0.29	.94	.20	.57
CT	1.76	0.25	1.71	0.33			
Mean loading rate bw/s							
MC	82.3	22.2	69.7	16.9	.07	.01	.32
CT	84.5	24.5	83.4	25.9			
Instantaneous loading rate, bw/s							
MC	125.2	45.3	105.4	22.5	.01	.86	.42
CT	113.4	35.8	115.8	38.6			
Peak positive tibial acceleration, g							
MC	6.9	3.3	6.3	3.2	.55	.00	.69
CT	5.5	2.2	5.4	2.9			
Peak-to-peak tibial acceleration, g							
MC	11.6	4.2	11.8	4.8	.56	.00	.96
CT	10.1	2.5	9.7	3.7			
Lower extremity stiffness, kN/m							
MC	9.1	2.0	8.5	1.5	.63	.02	.28
CT	8.9	1.8	8.3	1.5			

^aMC, motion control; CT, cushion trainer; bw, body weight.

CT compared with MC. Peak positive tibial acceleration was significantly reduced by 20% in the CT compared with the MC. Peak-to-peak tibial acceleration was also significantly reduced by 16% in the CT compared with the MC.

Unexpectedly, mean loading rate was significantly reduced in the MC compared with the CT shoe. Lower extremity stiffness was significantly higher in the MC, although only a 2% difference was noted.

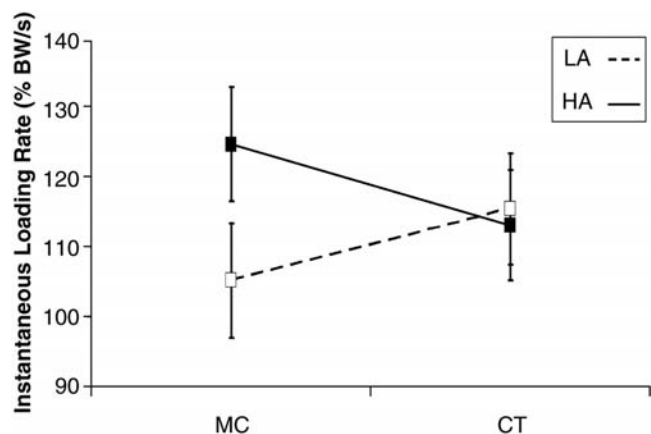


Figure 6. Interaction of footwear and arch height for instantaneous loading rate. Solid line is the HA; dashed line is the LA; error bars indicate standard error of the measurement. HA, high arch; LA, low arch; bw, body weight.

DISCUSSION

The purpose of this study was to investigate the interaction of arch height and footwear on lower extremity mechanics during running. In support of our hypotheses, the MC did reduce rearfoot motion compared with the CT; however, these effects were not greater for the LA compared with the HA. Similarly, as hypothesized, the CT reduced tibial shock and loading variables compared with the MC; however, there was not a differential response between the arch types. Contrary to our original hypothesis, lower extremity stiffness was reduced in the CT compared with the MC, and footwear did not have an effect on knee stiffness. These findings will be discussed separately.

Interaction of Shoe and Arch Type

A significant interaction was noted for instantaneous loading rate. As expected, instantaneous loading rate was decreased in the CT for the HA runners. Contrary to expectation, this variable actually increased in the CT for the LA runners (Figure 6). It was expected that instantaneous loading rate would be lower for both groups when running in the CT but that the effect would be greater in the HA runners. However, based on these findings, one might suggest that running in the traditionally recommended shoe (CT for HA, MC for LA) for arch type results in a lowering of the instantaneous loading rate.

No other interactions were found. These results were surprising in light of the findings by Knapik et al,¹⁸ who reported a decrease in injuries after the footwear recommendation program that was based on foot type. A closer look at this study revealed a follow-up survey on 1.3% (n = 122) of the recruits. This survey suggested that 71% of the soldiers did purchase shoes, and of those soldiers, only 11% of those surveyed reported following the footwear recommendation when buying new shoes. Unfortunately, the study did not have a true control group, which would be needed to determine whether the reduction in injuries was simply owing

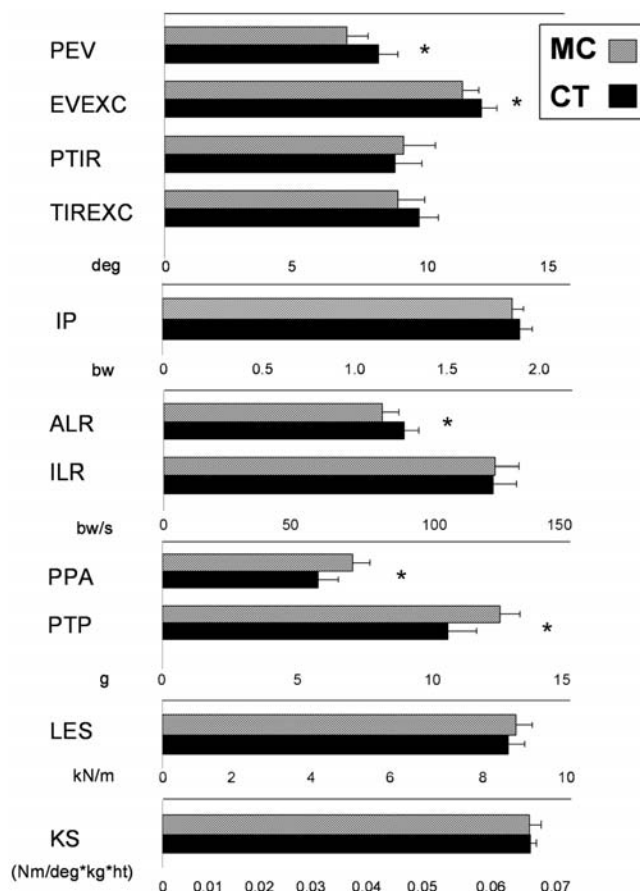


Figure 7. Main effects for the variables of interest. *Denotes a significant difference between shoe conditions: motion control (MC) and cushion trainer (CT). PEV, peak eversion; EVEXC, eversion excursion; PTIR, peak tibial internal rotation; TIREXC, tibial internal rotation excursion; IP, impact peak; ALR, average loading rate; ILR, instantaneous loading rate; PPA, peak positive acceleration; PTP, peak-to-peak acceleration; LES, lower extremity stiffness; KS, knee joint stiffness in the sagittal plane; bw, body weight.

to new footwear. Previous research has suggested that the implementation of new shoes alone has been shown to reduce stress fractures in Marines during a 12-week training program,^{11,17} and these authors recommended that future studies involving footwear recommendations should use a randomized prospective design to more accurately determine the program's effectiveness.

Main Effect of Shoe

A number of significant main effects for shoe were noted. Peak eversion was reduced by 1.1° in the MC compared with the CT (Figure 8). Eversion excursion was reduced by 0.7° in the MC compared with the CT. Data obtained on peak eversion and eversion excursion were similar to values that have previously been reported.^{1,31} Although these findings were significant, they were less than that noted of previous studies examining shoes with different midsole hardness values.

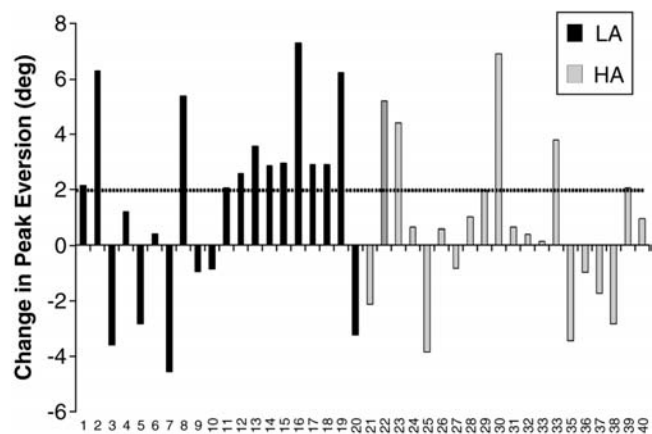


Figure 8. Subject-specific changes in peak eversion (a positive number represents a reduced peak eversion value for the motion control shoe). Low-arched (LA) runners represented by black bars; high-arched (HA) runners represented by gray bars; dotted line represents 2° reduction in motion control shoe.

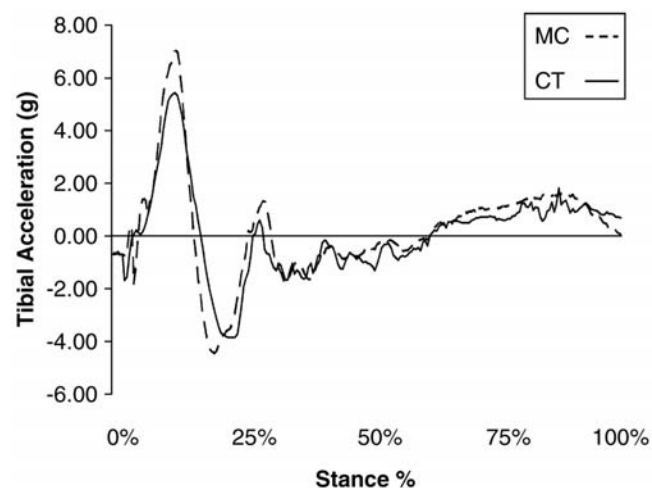


Figure 9. Representative graph of tibial shock in a runner showed a reduction in peak positive acceleration and peak-to-peak acceleration in the cushion trainer (CT) shoe compared with the motion control (MC) shoe.

Reductions of 3.8° to 5.3° have been noted when subjects ran in shoes with stiffer midsoles.^{6,14} These larger reductions may be owing, in part, to methodological difference in measuring rearfoot motion. Both Hamill et al¹⁴ and DeWit et al⁶ placed markers directly on the heel counter of the shoe. This method has been shown to result in greater overall motion compared with markers placed directly on the calcaneus.²⁸ This appeared to be the case, as the total rearfoot motion in the study performed by Hamill et al¹⁴ was 14.5°, compared with 11.5° observed in the current study. In addition, the shoes used by Hamill et al¹⁴ and DeWit et al⁶ had greater differences in midsole stiffness than did the 2 shoes used in this study. Although the relevance of less than a degree for eversion excursion may be questioned, the reduction in peak

eversion, when repeated during thousands of foot strikes, may be important in reducing the risk of injury.

With regard to the impact variables, peak positive tibial acceleration was reduced by 1.2 g and peak-to-peak tibial acceleration by 1.8 g in the CT shoe compared with the MC shoe (Figure 9). The values for peak positive tibial acceleration are similar to those observed by Mercer et al.^{21,22} Both arch types experienced a reduction in shock in the CT. Because HA runners have been reported to experience higher loading, increasing their risk for bony injuries, running in a CT may be more critical for an HA runner than for an LA runner.³⁰

Although lower extremity stiffness was significantly higher in the MC condition, the increase was only 2%, and the effect size was small (0.12). This small increase is not likely to be clinically relevant. Evaluation of knee joint stiffness data also revealed no differences between the shoe conditions. Other landing studies reported much greater differences in lower extremity stiffness when landing on hard and soft surfaces. This may be owing to a greater difference in the surface stiffness values compared with the difference in stiffness between the 2 shoes evaluated in the current study.

There are a number of possible limitations to this study. First, all of the subjects were examined in a rested state. It is possible that footwear has a greater effect on mechanics as the runner becomes fatigued. In addition, the footwear chosen for arch type may not have been ideal for all subjects. We purposely chose the most extreme MC and CT shoes. The MC shoe chosen is designed for extreme overpronators with body mass greater than 102 kg. Subjects who do not pronate as much and weigh less are often recommended to wear a stability shoe as opposed to an MC shoe. The MC shoe may therefore have been too rigid for some of the LA runners. A study using extreme MC and CT shoes might yield greater differences if runners with extreme pronation or excessive shock were targeted as opposed to those with solely low and high arches.

It may be more important to match footwear to mechanics rather than arch type. Although there are associations between arch type and mechanics, arch type does not necessarily dictate mechanics. Thus, it may be important to screen runners' mechanics to optimally match them to the footwear that would reduce their risk for sustaining an overuse injury. This might be done using simplified versions of real-time analyses of rearfoot motion and tibial shock at running shoe stores. Alternatively, "smart" shoes may evolve that tune themselves to the runner's mechanics to provide optimal CT/MC for that runner.

In conclusion, aside from the instantaneous loading rate, no interaction of arch type and footwear was observed. However, expected main effects were noted for the footwear. In the MC shoe, a decrease in rearfoot motion was noted, whereas in the CT shoe, a decrease in tibial shock was observed, regardless of arch type. Nevertheless, unless a mechanical analysis suggests otherwise, we continue to recommend empirically an MC shoe for the LA runners, who are prone in general to overuse injuries associated with increased rearfoot motion, and a CT shoe for the HA runners, who are in general prone to higher loading rates and the bony injuries associated with these variables.

ACKNOWLEDGMENT

This project was supported by the American College of Sports Medicine Doctoral Student Research Grant. The authors also acknowledge New Balance Athletic Shoes for donating the footwear used in the study.

REFERENCES

- Butler RJ, Davis IM, Laughton CM, Hughes M. Dual-function foot orthosis: effect on shock and control of rearfoot motion. *Foot Ankle Int.* 2003;24:410-414.
- Butler RJ, Hillstrom H, Song J, Richards C, Davis IS. The Arch Height Index Measurement System: establishment of reliability and normative values. *J Am Podiatry Assoc.* In press.
- Clarke TE, Fredrick EC, Cooper LB. Effects of shoe cushioning upon ground reaction forces in running. *Int J Sports Med.* 1983;4:247-251.
- Cohen J. *Statistical Power Analysis for the Behavioral Sciences.* 2nd ed. Hillsdale, NJ: Lawrence Erlbaum; 1988.
- deKoning JJ, Nigg BM. Kinematic factors affecting impact peak vertical ground reaction force in running. *J Biomech.* 1994;27:673.
- DeWit B, De Clerq D, Lenoir M. The effect of varying midsole hardness on impact forces and foot motion during foot contact in running. *J Appl Biomech.* 1995;11:395-406.
- Ekenman I, Milgrom C, Finestone C, et al. The role of biomechanical shoe orthoses in tibial stress fracture prevention. *Am J Sports Med.* 2002;30:866-870.
- Esterman A, Pilotto L. Foot shape and its effect on functioning in Royal Australian Air Force recruits, part 2: pilot, randomized, controlled trial of orthotics in recruits with flat feet. *Mil Med.* 2005;170:629-633.
- Ferber R, McClay-Davis I, Williams DS III, Laughton C. A comparison of within- and between-day reliability of discrete 3D lower extremity variables in runners. *J Orthop Res.* 2002;20:1139-1145.
- Ferris DP, Lang K, Farley C. Runners adjust leg stiffness for their first step on a new running surface. *J Biomech.* 1999;32:787-794.
- Gardner LI, Dziados JE, Jones BH, et al. Prevention of lower extremity stress fracture: a controlled trial of a shock absorbent insole. *Am J Public Health.* 1988;78:1563-1567.
- Gerritsen KG, van den Bogert AJ, Nigg BM. Direct dynamics simulation of the impact phase in heel-toe running. *J Biomech.* 1995;28:661-668.
- Giladi M, Milgrom C, Stein M. The low arch: a protective factor in stress fractures. A prospective study of 295 military recruits. *Orthop Rev.* 1985;14:709-712.
- Hamill J, Bates BT, Holt K. Timing of lower extremity joint actions during treadmill running. *Med Sci Sports Exerc.* 1992;24:807-813.
- James S, Bates B, Osternig L. Injuries to runners. *Am J Sports Med.* 1978;6:640-650.
- Kaufman KR, Brodine SK, Shaffer RA, Johnson CW, Cullison TR. The effect of foot structure and range of motion on musculoskeletal overuse injuries. *Am J Sports Med.* 1999;27:585-593.
- Kerdok A, Biewener AA, McMahon TA, Weyand PG, Herr HM. Energetics and mechanics of human running on surfaces of different stiffnesses. *J Appl Physiol.* 2002;92:469-478.
- Knapik JJ, Feltwell D, Canham-Chervek M, et al. 2001. *Evaluation of Injury Rates During Implementation of the Fort Drum Running Shoe Injury Prevention Program.* Aberdeen Proving Ground, MD: US Army Center for Health Promotion and Preventive Medicine. 12-MA-6558-01.
- McMahon TA, Cheng GC. The mechanics of running: how does stiffness couple with speed? *J Biomech.* 1990;23:65-78.
- Mercer JA, Bates BT, Dufek JS, Hreljac A. Characteristics of shock attenuation during fatigued running. *J Sports Sci.* 2003;21:911-919.
- Mercer JA, Vance J, Hreljac A, Hamill J. Relationship between shock attenuation and stride length during running at different velocities. *Eur J Appl Physiol.* 2002;87:403-408.
- Milgrom C, Giladi M, Kashtan H, et al. A prospective study on the effect of a shock-absorbing orthotic device on the incidence of stress fractures in military recruits. *Foot Ankle.* 1985;6:101-104.
- Nigg BM, Liu W. The effect of muscle stiffness and damping on simulated impact force peaks during running. *J Biomech.* 1999;32:849-856.
- Perry SD, Lafortune MA. Influences of inversion/eversion of the foot upon impact loading during locomotion. *Clin Biomech (Bristol, Avon).* 1995;10:253-257.
- Radin EL, Ehrlich MG, Chernack R, Abernathy P, Paul IL, Rose RM. Effect of repetitive impulse loading on the knee joints of rabbits. *Clin Orthop Relat Res.* 1978;131:293-299.
- Simkin A, Leichter I, Giladi M, Stein M, Milgrom C. Combined effect of foot arch structure and an orthotic device on stress fractures. *Foot Ankle.* 1989;10:25-29.
- Snel JG, Delleman NJ, Heerkens YF, van Ingen Schenau GJ. Shock absorbing characteristics of running shoes during actual running. In: Winter DA, Norman RW, Wells RP, Hayes KC, Patla AE, eds. *Biomechanics IX-B.* Champaign, Ill: Human Kinetics Publishers; 1985: 133-137.
- Stacoff A, Reinschmidt C, Nigg BM, van den Bogert AJ, Lundberg AJ, Stussi E. Effects of shoe sole construction on skeletal motion during running. *Med Sci Sports Exerc.* 2001;33:311-319.
- Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A prospective study of running injuries: the Vancouver Sun Run "InTraining" clinics. *Br J Sports Med.* 2003;37:239-244.
- Williams DS, McClay IS. Measurements used to characterize the foot and the medial longitudinal arch: reliability and validity. *J Orthop Sports Phys Ther.* 2000;80:864-871.
- Williams DS, McClay IS, Baitch S. Effect of inverted orthoses on lower-extremity mechanics in runners. *Med Sci Sports Exerc.* 2003; 35:2060-2068.
- Williams DS, McClay IS, Hamill J. Arch structure and injury patterns in runners. *Med Sci Sports Exerc.* 2001;16:341-347.
- Williams DS, McClay IS, Hamill J, Buchanan TS. Lower extremity kinematic and kinetic differences in runners with high and low arches. *J Appl Biomech.* 2001;17:153-163.