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Foot orthotic devices to modify selected aspects of lower extremity mechanics*

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ABSTRACT

Excessive foot pronation has been speculated to be a cause of leg and foot problems among runners. Foot orthotic devices are often used to modify this condition. Examination of the records of 180 patients treated for various running injuries showed that 83 individuals (46%) were prescribed orthotic devices and that 65 of these runners (78%) were able to return to their previous running programs. In order to assess further the effects of this type of orthotic device, six runners were selected from this group and filmed using two cameras (200 frames/sec) under three conditions: (1) barefoot, (2) regular shoe, and (3) regular shoe plus orthotic device. Both the period of pronation and the amount of maximum pronation were significantly reduced by using the foot orthotic device. The data support the conclusion that foot orthotic devices can be successfully used to modify selected aspects of lower extremity mechanics during the support phase of running.

Although a number of anatomical factors must be considered in the diagnosis and evaluation of lower extremity problems encountered by runners, it seems that many of these problems are related, either directly or indirectly, to foot structure and function during the support phase of the activity.[1-3]

In a recent clinical study, James et al.[1] identified some common problems experienced by 180 runners (Table 1). The data also indicated that 58% of the subjects examined exhibited pronated feet in the static weightbearing position. The major injury analysis is shown in Table 2. Additional observations indicated that the types of injuries associated with pronated feet were, in fact, similar to those found in the overall injury analysis. This would, however, suggest that there is a complex interaction between running injuries and anatomical factors and that excessive pronation is one major cause of foot and leg problems of runners.

The treatment modalities used on these runners are shown in Table 3. Eighty-three individuals (46%) wore prescribed orthotic devices as a form of treatment and 65 of these runners (78%) were able to return to their previous running programs. An orthotic appliance or device is a type of "shim" placed between the foot and shoe to modify foot position (not only pronation) during the support phase of running. Foot orthotics can be made either of a soft flexible material or a more rigid plastic material.

The purpose of this study was to assess further the effects of foot orthotic devices on selected aspects of foot and leg running mechanics by examining a small group of joggers-runners selected from the previously discussed clinical study. All subjects chosen were from the group classified as "pronators" and had been successfully treated with orthotic appliances.[1]

METHODS

Six joggers-runners (running 3 to 7 days per week; 10 to 110 km per week) who had used prescribed rigid foot orthotic devices for at least 1 year served as subjects for this study. All subjects had a history of various difficulties sufficiently severe to cause them to seek medical attention. Clinical evaluation of each condition indicated that an orthotic device might be helpful in overcoming the patient's problem(s). Foot casts were made and the appropriate orthotic device was constructed for each individual. All six subjects were eventually able to return to their normal jogging-running schedule.

While running on a treadmill subjects were filmed using two high-speed super 8-mm cameras (Visual Instrumentation Corporation, Model SP-1) operating at 198 to 205 frames per sec. Films were obtained of foot placement from the rear and of

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TABLE 1
The most common problems experienced in a study group of runners[1,a]

Problems	No. of runners	%
Knee pain	67	29
Posterior tibial syndrome (shin splints)	30	13
Achilles tendinitis	25	11
Plantar fasciitis	17	7
Stress fractures	14	6
Iliotibial tibial tract tendinitis	11	5

[a] From James et al.[1] In a group of 180 runners, 164 (71%) had lower extremity problems.

TABLE 2
Major injury analysis of a study group of runners[1,a]

Injury	No. of runners	%
Posterior tibial syndrome	13	15
Plantar fasciitis	13	15
Achilles tendinitis	10	12
Knee pain, no diagnosis	10	12
Chondromalacia	5	6

[a] From James et al.[1] In a study of 180 runners, 72 (58%) patients exhibited pronated feet in the static weightbearing position.

TABLE 3
Treatment modalities used for runners in study group[1,a]

Modality	% of patients
Rest	47
Orthotic device	46
Reduced mileage	26
Shoe change/modification	19
Steroid injection	17
Antiinflammatory agent	14
Surgery	5

[a] From James et al.[1] In a group of 180 runners, 164 (71%) had lower extremity problems which necessitated treatment.

lower limb movement from a lateral view. Subjects were filmed under three conditions: (1) barefoot, (2) test shoe, and (3) test shoe plus orthotic device. All runners wore the same type of shoes (Nike Boston) for testing. The speed chosen for each runner was based upon individual running ability rather than a fixed speed due to the widely varied capabilities of the individuals. Running speeds ranged from 2.82 m per sec (9:30 min per mile pace) to 4.47 m per sec (6 min per mile pace). Treadmill running was chosen instead of overground running in order to control foot placement and obtain several consecutive footfalls with a minimum amount of filming perspective error. To minimize differences that might exist between treadmill and overground running, all subjects participated in a supervised training session before being filmed.

Previous studies[4-6] have divided the support phase of running into three subphases, i.e., separated by the positions of heel strike, foot flat, and heel-off and toe-off. In a previous study,[7] six intermediate positions were identified based upon related joint functions. Important terms associated with these positions are given and defined in Table 4.

The films were evaluated using a stop action projector in conjunction with a Numonics Graphics Calculator interfaced to a Tektronix 4051 graphic system. All raw data were treated by using a cubic spline data fitting program prior to computation of final values. Data analysis consisted of the evaluation of a single right footfall for all subjects for the three previously described conditions.

Data analysis consisted of a relative temporal evaluation of selected events throughout the support phase, a kinematic analysis of selected body parts and joint functions, and graphic displays of the functional relationships between selected parameters. The data for the three test conditions were analyzed by using a one-way analysis of variance design with repeated measures and planned comparisons conducted between the three pairs of group means for each variable, $P < 0.15$. In addition, all data were compared to previously obtained results on a group of asymptomatic runners[7] by using a one-way analysis of variance design for independent groups. Planned comparisons were conducted between the barefoot and shoe conditions for each group, the orthotic and nonorthotic group, and the barefoot and shoe conditions, $P < 0.05$.

RESULTS AND DISCUSSION

Mean values describing the occurrence of selected events relative to the beginning of the support phase are presented in Table 5. Mean values from a previous study[7] are also given as well as significant comparisons between selected events and conditions.

Comparisons between the events of maximum knee flexion, maximum pronation, and patella cross for all conditions showed no significant differences. This finding is in agreement

TABLE 4
Terms and definitions used in analyses of lower extremity function in runners[7]

Terms	Definitions
Pronation	Eversion of the calcaneous relative to the midline of the lower leg. Measurement used to approximate the true action of pronation.
Supination	Inversion of the calcaneous relative to the midline of the lower leg. Measurement used to approximate the true action of supination.
Begin pronation	Neutral position of calcaneous when moving from a supinated to a pronated condition.
Maximum pronation	Position of greatest eversion of the calcaneous relative to the lower leg.
End pronation	Neutral position of calcaneous when moving from a pronated to a supinated condition.
Maximum knee flexion	When the angle formed by the leg and thigh assumes its smallest value.
Maximum ankle dorsiflexion	When angle formed by the leg and a line through the medial malleolus and first metatarsal head assumes its smallest value.
Patella cross	Position in which the patellas of both legs are in line with the lateral camera axis. Used to approximate total body center of gravity passing over base of support.

with previous results reported by Bates et al.[7] It would appear that these three events all occurred at or near the position when the center of gravity passes over the base of support.

When comparing the experimental conditions, significant differences were observed for four events between the barefoot and orthotic conditions. For each of these events, the mean value for the shoe condition was observed to be an intermediate value. Pronation began later and ended sooner with the use of the orthotic device.

In comparing these data with previously obtained data for normal or asymptomatic runners, it should be noted that for the events of begin pronation, end pronation, and period of pronation, all between group comparisons were significantly different except begin pronation and the period of pronation between the barefoot conditions for both groups. The relationships of these events, including the occurrence of maximum pronation, are shown graphically in Figure 1. The data suggest that the use of the orthotic device caused adjustments of the functional mechanisms of the joint and produced observed values in the orthotic group that were similar to those previously observed in the normal group. The between group comparisons between the barefoot and shoe conditions were all significant. These data support the premise that a simple shoe can produce significant changes in the events used to define foot function.

A final observation of some importance was the occurrence of maximum ankle dorsiflexion later in the support phase as the result of wearing an orthotic device. It would seem that the reorientation of the heel allowed the body to move forward longer before the maximum dorsiflexion value was reached and the heel was forced to raise from the running surface.

Table 6 contains the mean angular values describing the positioning of selected body parts. Significant differences that occurred between mean values for various conditions are also presented as well as mean values from a previous study.[7]

The use of the orthotic device resulted in a significant reduction in maximum pronation compared to the barefoot condition. In addition, all comparisons between the orthotic group and the normal group were significant, indicating that the groups did differ in maximum pronation for all conditions evaluated. However, with the use of an orthotic device the injured group mean value of maximum pronation (7.0°) was approximately equal to that of normal subjects wearing only a regular shoe (7.2°) and their injury problems were eventually resolved.

The observed changes in the values of maximum pronation were primarily the result of reorientation of the heel relative to the running surface. The orientation of the leg remained nearly constant. It is important to note, however, that increases in

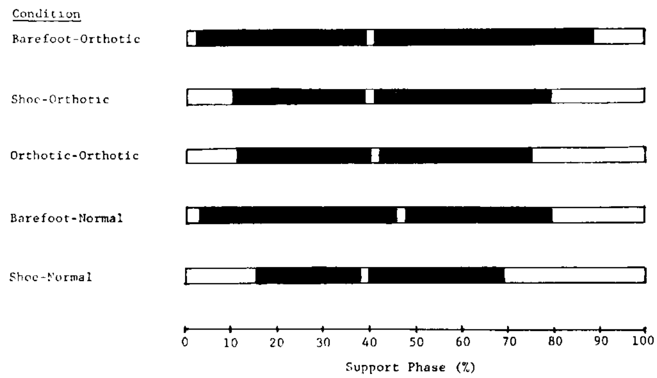

Fig. 1. *Comparisons between relative periods of pronation for selected conditions.*

TABLE 5

Mean values of selected events occurring during the support phase of running[a]

Event	Orthotics (n = 6)			Normals (n = 10)[b]	
	Barefoot	Shoe	Orthotic	Barefoot	Shoe
Begin pronation	1.23[c]	9.96	10.62[d]	3.43	15.06
	(3.00)	(4.19)	(6.88)	(2.39)	(4.88)
Maximum knee flexion	35.36[c]	42.20	40.50	37.05	40.40
	(4.66)	(4.09)	(3.93)	(4.82)	(3.76)
Maximum pronation	39.72	39.73	40.76	46.84	38.58
	(6.83)	(3.71)	(4.47)	(7.21)	(3.35)
Patella cross	39.66	42.43	40.26	39.79	39.41
	(5.23)	(5.51)	(6.94)	(5.30)	(3.71)
Maximum ankle dorsiflexion	49.39	53.06[f]	55.67[d]	49.62	51.15
	(3.62)	(1.72)	(2.18)	(4.43)	(1.77)
End pronation	88.28	79.49	74.37[d]	79.90	69.03
	(7.54)	(12.29)	(8.77)	(3.92)	(7.58)
Period of pronation	87.06	69.54	63.75[d]	76.69	53.97
	(9.89)	(15.79)	(12.42)	(5.79)	(11.38)

[a] All values are expressed as percentage of time from beginning of support phase. Numbers in parentheses indicate standard deviations.
[b] Data for normals taken from Bates et al.[7]
[c] Significant difference between barefoot and shoe, $P < 0.15$.
[d] Significant difference between barefoot and orthotic, $P < 0.15$.
[e] No significant differences between these events.
[f] Significant difference between shoe and orthotic, $P < 0.15$.

TABLE 6

Comparisons of mean angular values of selected body parts occurring within the support phase of running[a]

Event	Orthotics (n = 6)			Normals (n = 10)[b]	
	Barefoot	Shoe	Orthotic	Barefoot	Shoe
Maximum pronation	13.0	11.0	7.0[c]	8.6	7.2
	(3.17)	(4.82)	(4.25)	(2.20)	(2.30)
Posterior shank at maximum	80.1	79.6[d]	80.4	81.6	81.3
pronation	(3.12)	(3.69)	(3.91)	(2.20)	(2.20)
Heel at maximum pronation	93.1	90.5	87.4[c]	89.8	88.6
	(2.70)	(4.69)	(2.97)	(1.81)	(1.65)
Maximum knee flexion	139.2	137.4	138.4	143.1	141.6
	(2.66)	(3.36)	(2.85)	(5.60)	(5.30)
Maximum ankle dorsiflexion	93.9[e]	90.5	90.0[c]	100.5	96.7
	(2.43)	(1.82)	(2.54)	(4.40)	(4.30)

[a] Posterior values are for right leg; all values are expressed in degrees. Numbers in parentheses indicate standard deviations.
[b] Data for normals taken from Bates et al.[7]
[c] Significant difference between barefoot and orthotic, $P < 0.15$.
[d] Significant difference between shoe and orthotic, $P < 0.15$.
[e] Significant difference between barefoot and shoe, $P < 0.15$.

running speed can cause increases in maximum pronation as a result of changes in leg orientation.[7]

Examination of the data on comparisons between the values of maximum ankle dorsiflexion indicated a strong relationship between this variable and pronation. All comparisons between the various conditions and groups except one (shoe *versus* orthotic) showed significant differences. Several observations are worth noting: (1) reductions in maximum pronation within each group were always accompanied by reductions in maximum ankle dorsiflexion; (2) the normal group had greater ankle dorsiflexion, but lesser corresponding values for maximum pronation; and (3) the barefoot condition values were always greater than the shoe condition values. In addition, there was a significant difference between the orthotic and normal groups on maximum knee flexion, with the orthotic group having greater flexion.

Explanations for this finding are speculative. The orthotic group may have lacked ankle flexibility due to tight gastrocnemius musculature. In an attempt to gain greater ankle dorsiflexion they shortened the gastrocnemius by additional knee flexion. This was not sufficient, however, and they may have been forced to pronate more as an additional compensating mechanism. It is also possible that this group may have pronated excessively to compensate for some other condition (tibia varum, subtalar varus, or forefoot supination) and no longer had a need to dorsiflex as much. In reality, however, it was observed that the runners in the orthotic group as well as others in the clinical study[1] that were classified as pronators usually experienced a combination of two or more of these conditions.

One final observation is that the effect of a slightly positive heel (about 8 mm) reduced the period of pronation as well as the amount of maximum pronation and maximum ankle dorsiflexion. About 75% of the mean reduction in maximum ankle dorsiflexion resulting from a positive heel shoe was directly accounted for by the geometry of the two conditions. The addition of an orthotic device further elevates the heel but it also reorients it.

Figures 2 to 4 contain graphic displays of the functional

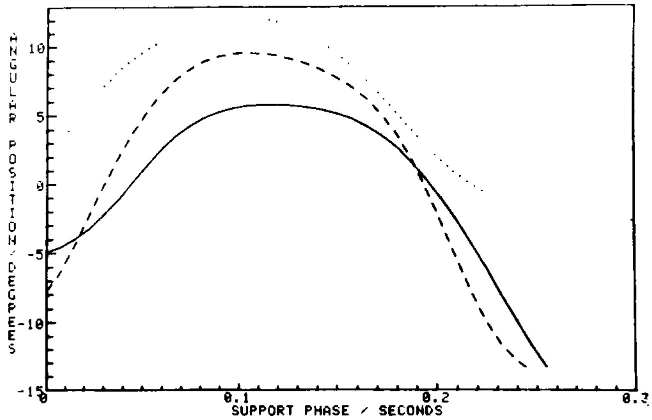

Fig. 2. *Pronation-supination relationship for the support leg barefoot (· · · · ·), with shoe (– – –), and with orthotic device in shoe (——).*

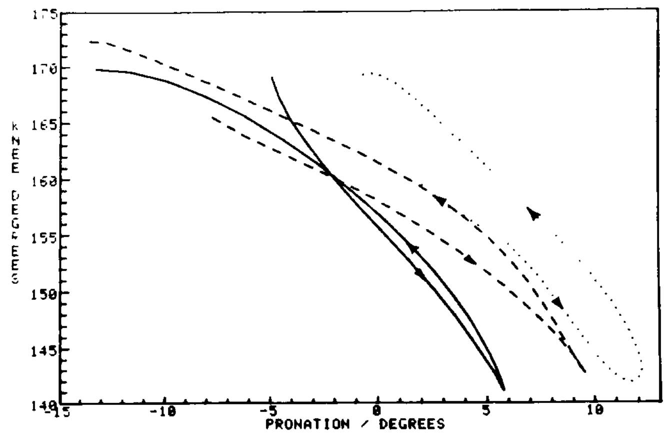

Fig. 3. *Comparison between pronation and knee flexion of the support leg barefoot (· · · · ·), with shoe (– – –), and with orthotic device in shoe (——).*

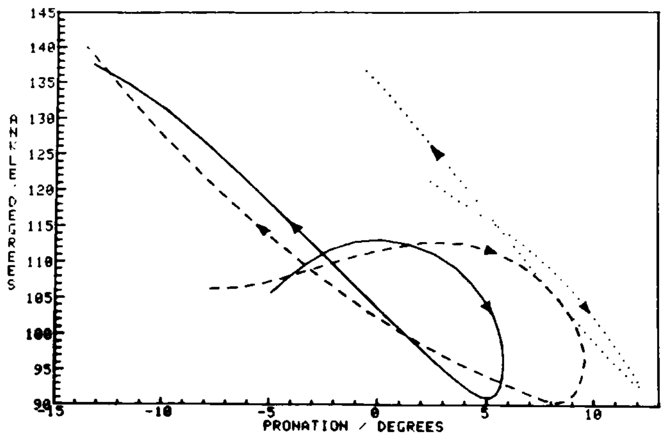

Fig. 4. *Comparison between pronation and ankle flexion for the support leg barefoot (·····), with shoe (- - -), and with orthotic device in shoe (——).*

relationships between selected parameters obtained for a single subject whose data values are representative of the mean values. Figure 2 shows the reductions in maximum pronation that resulted from a shoe and the shoe with the orthotic device. Examination of Figures 3 and 4 shows similar relationships for all three conditions, with greater changes having occurred between the barefoot condition and the other two conditions. Another primary difference was seen in the shifting of the curves to the left which was the result of the reduction in pronation.

The functional mechanisms evaluated in this study were different for the three conditions. The orthotic device used by the injured runners modified their lower extremity mechanics in such a way that the observed values were similar to those measured on noninjured runners wearing only a simple shoe. Major changes were observed in both the amount and period of pronation, and these changes seemed to alleviate these runners' problems.

These findings imply that functional foot mechanics seem to be dependent upon the shape, characteristics, and fit of the materials we place between our feet and the running surface. Care must be taken that overmodifications do not create new problems. Elimination of pronation requires that the normal stresses of running be absorbed by some other mechanism. Since pronation is a necessary functional mechanism, only when it results in injury should attempts be made to modify it.

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