Nomenclature

Pronation—Eversion of the calcaneus relative to the midline of the lower leg. Measurement used to approximate the true action of pronation.

Heel contact—When the heel of the shoe makes first contact on the treadmill.

Maximum pronation—Position of greatest eversion of the calcaneus relative to the lower leg.

Total rear foot movement—The value obtained by adding the angle of the foot at heel contact and maximum pronation angle.

Maximum rate of pronation—The time from heel contact to the maximum pronation in degrees/second.

Reverse 8-stirrup—A new taping method combining a figure eight (partial) and the traditional stirrup technique.

Low-dye—A taping method designed to reduce strain on the plantar fascia and medial arch structures, and to help control excessive pronation.

Foot orthotic device—Semirigid appliance placed between the foot and shoe to modify foot position during the support phase of gait.

Shoe—no support—No additional support or device in the athlete’s running shoe.

Patellar tendinitis, iliotibial band syndrome, metatarsal stress syndrome, and nonspecific back pain are frequently associated with the so-called pronated foot (10, 12, 23, 25).

Newell and Nutler (18) found excessive pronation to be the main cause of chronic overuse injuries. Lutter (16) found that of 213 running knee injuries, 43% were pronation related. Cooper (11) attributed a moderately pronated foot to pain in the areas of the metatarsal heads, knees, hips, and low back. Halback (15) viewed the pronated foot as “one possible structural and biomechanical problem that can cause low back pain, hip pain, knee pain and foot pain” (p. 53). Roy and Irvin (22) related excessive pronation to Morton’s neuroma and stress fractures of the metatarsals. A positive correlation between pronation and the incidence of “shinsplints” was found by DeLacerda (13).

The management of the athlete with these syndromes, using orthotics, has been described by Bates et al. (1, 2, 3), Rogers et al. (20), Smith et al. (24), and Newell and Nutler (18). The studies relating rear foot movement to orthotic use have produced mixed results. Smith et al. (24), Cavanagh (5), and Clarke et al. (9) have shown that the insertion of various “medial support” devices significantly reduces maximum pronation observed. Bates et al. (2) and Rogers et al. (20) found no significant change in maximum pronation with the introduction of orthoses into their subjects’ shoes. Scranton (23) concluded that the low-dye taping technique altered forces under the foot to the extent that early symptoms of common overuse syndromes might be effectively treated.

The most commonly used means of quantifying rear foot movement is by digitization of high-speed film data. Bates et al. (1, 2, 3), Rogers et al. (20), Smith et al. (24), Newell and Nutler (18), Clarke et al. (8, 9), and Cavanagh et al. (5, 6, 7) analyzed high-speed film to measure the relative movement of the
rear foot (calcaneus) and the lower leg to determine the degree of pronation exhibited during running at various speeds.

Such analysis involves filming the eversion or inversion of the calcaneus relative to the lower leg from behind the subject. By monitoring the position of the calcaneus relative to the lower leg in the frontal plane throughout foot contact, researchers have shown that shoe design (5, 8), orthoses (2, 3, 5, 9, 19, 20, 24), taping (9, 23), and the shoe itself (1, 19, 24) can affect the amount of maximum pronation that is observed.

The purpose of this study was to compare the effects of four different treatments on the control of the amount and rate of foot pronation while running. The four treatments were the reverse 8-stirrup taping technique (17), the low-dye taping technique (22), prescribed rigid orthotic devices, and no support in the running shoe.

Methods

Subjects

Six intercollegiate cross-country runners (3 males, 3 females), age 20–22 years, who had used prescribed rigid foot orthotic devices for at least 2 years served as subjects for this study. The subjects were well-trained distance runners who had no injuries and were symptom-free at the time of data collection. Informed consent of the subjects was obtained in accordance with the policy statement of the American College of Sports Medicine and the Bowling Green State University Human Subjects Review Board.

Test Procedure

Reference points on each subject’s calf midline, Achilles tendon, midcalcaneus, and bottom center of the shoe heel cup were marked with a black magic marker, so that a 6-mm diameter black dot was visible (Figure 1). These markings were similar to those used by Clarke, Frederick, and Hamill (8) and others (6, 9, 24). Before each test run, a pretest standing stance of each subject was filmed with the feet 16 cm apart (8). The standard of 16 cm was kept constant by the use of a wooden block placed between each subject’s feet. After each subject completed the test runs, a posttest standing stance was filmed to determine if there was any significant breakdown of the tape and movement of the foot from the pretest stance filming.

The subjects were filmed from behind (200 fps) while running on a treadmill at speeds of 4.47 m/s (6-min mile pace) for males (3, 24) and 3.8 m/s (7-min mile pace) for females (8, 24). The treadmill was chosen instead of overground running to ensure consistency of foot placement and running velocity as well as to obtain several consecutive footfalls with a minimum of perspective error. To minimize differences that might exist between treadmill and overground training, all subjects participated in a 1/2-hr supervised training session on this treadmill prior to being filmed.

Two filming sessions were performed, which included a total of four test runs. The first session consisted of filming the subjects (a) taped with the reverse 8-stirrup technique (17) (Figure 2) and (b) wearing the prescribed rigid orthotic. The second session consisted of filming the subjects (a) taped with the low-dye
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Figure 1 — Reference markers bisect the lower leg and heel, and the resultant rear foot angle is measured. Pronation is demonstrated at \(-10^\circ\), neutral, and supination at \(4^\circ\).

Each session began with a 5-min warm-up on the treadmill at a 3.8 m/s pace for males and 3.13 m/s pace for females. The warm-up period was used to acclimate the subjects to the tape and treadmill. Every subsequent minute the speed of the treadmill increased 0.17 m/s until the filming pace was attained. After 2 min at the achieved pace, a 3- to 4-s filming was taken at 200 fps (8, 24) with a high-speed LOCAM II camera, Model 51-0002 (Visual Instrumentation Corporation, Springfield, OH). The second test run of both sessions did not have a 5-min warm-up. The treadmill speed was once again set at a pace of 3.8 m/s for males and 3.13 m/s for females and increased 0.17 m/s each subsequent minute until the filming pace was attained. Upon completion of 2 min at this speed, the runners were once again filmed for 3–4 s. Kodak Tri-X reversal film was used for each filming session.

Data Analysis

The film data were analyzed with the Vanguard Motion Analyzer (Vanguard Instrument Corporation, Melville, NY) in conjunction with a Numonics Graphic Calculator, Model 1224 (Numonics Corporation, Lansdale, PA), interfaced to an Apple IIC personal computer. A specific software program was used to determine the angle of the axes to the lower leg and heel to the vertical. These two angles were then compared, and the difference between them was called the rear foot angle. In the reference system, a positive difference indicated that the heel was inverted relative to the lower leg, and this implied a supinated position. Con-
A. Anchor strip. B. Traditional stirrup for eversion ankle sprains.

C. First reverse 8-stirrup begins with a horizontal strip above the lateral malleolus.

D. First reverse 8-stirrup continues from a partial figure eight into a medial stirrup.

E. Second reverse 8-stirrup. Overlap at least one-half of the preceding reverse 8-stirrup.

F. Second reverse 8-stirrup continued. Two to four reverse 8-stirrups may be used to ensure the final reverse 8-stirrup runs directly over the navicular.

G. Anchor strips. Anchor distal to proximal.

H. Lateral heel lock.

I. Medial heel lock.

Figure 2 — Reverse 8-stirrup taping technique. Reprinted with permission of the Journal of Athletic Training, Vol. 27, pp. 86-87, 1992.
A. Anchor tape to the lateral border just proximal to the fifth metatarsal head. Continue around the heel and lightly applied to the first metatarsal head.

B. The plantar aspect of metatarsal heads 2 to 5 are supported by the thumb, and the first metatarsal head is depressed in a plantar direction by the index and middle fingers. Keep the foot in a neutral position. Secure the tape just proximal to the medial aspect of the first metatarsal head.

C. Repeat procedures A and B three to four times.

D. Anchor these strips down with circumferential strips running from the dorso-lateral aspect of the foot to the dorso-medial aspect.

Figure 3 — Low-dye taping procedures. From Roy/Irvin, SPORTS MEDICINE: Prevention, Evaluation, Management, and Rehabilitation. © 1983, p. 58. Adapted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.

versely, a negative difference indicated that the heel was everted relative to the lower leg, and this implied a pronated position (Figure 1). A similar reference system has been used previously by Cavanagh (7), Smith et al. (24) and Clarke et al. (8, 9).

Data analysis consisted of the evaluation of three right and left footfalls for all subjects for the four previously described conditions. Means and standard deviations were computed for all data sets. A $2 \times 4$ two-way MANOVA with repeated measures was used. The two independent variables were the right and left foot and the repeated measures were the four different treatment conditions (reverse 8-stirrup, low-dye, rigid orthotics, and shoes—no support). The dependent variables were maximum pronation, total rear foot movement, and maximum rate of pronation. The data for the four treatment conditions were also analyzed
with a one-way ANOVA with repeated measures and planned comparisons conducted between the four pairs of group means for each variable. Tukey’s test of alpha level 0.05 was used to determine significant differences.

**Results**

The MANOVA indicated that there were no significant ($p < .05$) overall treatment effects for the dependent variables (maximum pronation, total rear foot movement, and maximum rate of pronation). There were also no significant differences between the right and left feet. An ANOVA was conducted to determine if any treatment effect was significantly different for each dependent variable. Right and left foot results were combined since the MANOVA showed no significant difference between the two. The overall means and standard deviations describing the selected events are presented in Table 1.

The ANOVA indicated that the shoes-no support and low-dye taping techniques showed a significantly ($p < .05$) greater degree of maximum pronation than the reverse 8-stirrup. The reverse 8-stirrup also had significantly fewer degrees of total rear foot movement when compared to the low-dye taping technique ($p < .05$). There was no significant decrease of support for both the reverse 8-stirrup (pretest $-2.34^\circ \pm 3.31$; posttest $-2.90^\circ \pm 3.24$) and low-dye taping technique (pretest $-3.95^\circ \pm 3.64$; posttest $-4.37^\circ \pm 3.35$) after the treadmill run. No other significant comparisons between the treatments and dependent variables were realized.

**Discussion**

One problem that arises when one is studying the rear foot movement of subjects running in shoes is the midline of the calcaneus estimated from two markers placed vertically on the rear of the shoe (Figure 1). Nigg et al. (19) compared the movement of the heels and shoes of 9 subjects by cutting windows in the rear of each subject’s test shoe. They showed that heel and shoe movements are well correlated although an offset can exist. Smith et al. (24) conducted a similar

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Maximum pronation ($^\circ$)</th>
<th>Total rear foot movement ($^\circ$)</th>
<th>Maximum rate of pronation ($^\circ$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>Shoes-no support</td>
<td>16.4</td>
<td>4.5</td>
<td>19.0</td>
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<td>Foot orthotic device</td>
<td>15.6</td>
<td>4.1</td>
<td>18.3</td>
</tr>
<tr>
<td>Reverse 8-stirrup</td>
<td>13.7</td>
<td>3.6*</td>
<td>15.2</td>
</tr>
<tr>
<td>Low-dye</td>
<td>16.7</td>
<td>3.4</td>
<td>20.4</td>
</tr>
</tbody>
</table>

\*\(F(3, 15) = 3.97, p \leq .028\); Tukey $p < .05$. \(F(3, 15) = 4.03, p \leq .027\); Tukey $p < .05$. 

Table 1

Means and Standard Deviations of Rear Foot Movement
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study of 10 subjects in which clear heel counters were built into shoes. It was found that shoe and heel followed similar angular excursions. Therefore, the method of inferring heel movement from markers placed on the shoe, as used in the present study, is a valid and reliable method to determine rear foot movement.

A question that arises in the interpretation of the results of this study is the application of results obtained from subjects tested on the treadmill versus those running over ground. Clarke et al. (8) compared rear foot data obtained from the same subjects running at 3.8 m/s on ground and on a treadmill. No significant difference was found between treadmill and on-ground scores for maximum pronation and maximum rate of pronation. These findings indicate that there is no systematic change in maximum pronation or maximum rate of pronation as a result of running on a treadmill. Significant correlations ($N = 10$, $p < .05$) between the sets of scores were 0.72 (maximum pronation) and 0.68 (maximum rate of pronation). From these data, it appears that the results obtained in the present study should be applicable to running over ground.

The results obtained from the present study indicated that maximum pronation, total rear foot movement, and maximum rate of pronation were greater overall than the range of results reported in previous studies (2, 20, 24) (Table 2). Smith et al. (24) found that subjects ($N = 9$) tested under the shoes–no support condition displayed $11.3^\circ \pm 2.8$, $16.3^\circ \pm 3.7$, and $540^\circ /s \pm 167$ for maximum pronation, total rear foot movement, and maximum rate of pronation, respectively. The present study showed $16.4^\circ \pm 4.5$, $19.0^\circ \pm 6.9$, and $515.8^\circ /s \pm 159.5$ for maximum pronation, total rear foot movement, and maximum rate of pronation, respectively, for shoes–no support. Since the subjects for the present study were all excessive pronators these differences are appropriate.

The studies relating rear foot movement to orthotic use have produced mixed results. Smith et al. (24), Cavanagh (5), and Clarke et al. (9) have shown that the insertion of various “medial support” devices significantly reduces maximum pronation observed. Bates et al. (2) and Rogers et al. (20) found no significant change in maximum pronation with the introduction of orthoses into

### Table 2

**Means and Standard Deviations of Rear Foot Movement**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Maximum pronation ($^\circ$)</th>
<th>Total rear foot movement ($^\circ$)</th>
<th>Maximum rate of pronation ($^\circ$/s)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Shoes</td>
<td>11.3</td>
<td>2.8</td>
<td>16.3</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>11.0</td>
<td>4.8</td>
<td>15.9</td>
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</tr>
<tr>
<td>Foot orthotic devices</td>
<td>10.1</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.0</td>
<td>4.3</td>
<td>7.9</td>
<td>3.1</td>
</tr>
</tbody>
</table>
their subjects' shoes. The results of the present study indicate that the prescribed rigid orthotics did not significantly change maximum pronation, therefore, agreeing with the results from both Bates et al. (2) and Rogers et al. (20).

Scranton (23) concluded that the low-dye taping technique altered forces under the foot to the extent that early symptoms of common overuse syndromes may be effectively treated. The results of the present study indicated that the low-dye taping would not be the best choice of treatment for symptoms of excessive pronation. The low-dye taping had a significantly greater degree of maximum pronation ($p < .05$) and total degree of rear foot movement ($p < .05$) when compared to the reverse 8-stirrup taping technique. The results also indicated that there was no significant decrease of support for both the reverse 8-stirrup and low-dye taping techniques after the treadmill run. Therefore, according to the results of the present study, the reverse 8-stirrup would be as effective a treatment for excessive pronation in runners as the prescribed rigid orthotic devices.

Since the subjects of the present study were excessive pronators who used rigid orthotics, further studies comparing the reverse 8-stirrup are needed with individuals who are mild and moderately pronated. Further investigations of a larger population are also recommended.

**Conclusions**

Based on the findings of this study, we concluded the following:

- The reverse 8-stirrup taping technique significantly reduced the amount of maximum pronation and degrees of total rear foot movement when compared to the low-dye taping technique.
- The prescribed rigid orthotic treatment showed no significant difference when compared to the other treatments.
- The maximum rate of pronation showed no significant difference between treatments.
- The reverse 8-stirrup would be as effective a treatment for excessive pronation in runners as the prescribed rigid orthotic device.

**References**

6. Cavanagh, P.R., G.C. Andrew, R. Kram, M.M. Rogers, D.S. Sanderson, and M.


**Acknowledgments**

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