Journal of Athletic Training 2000;35(1):38–43
© by the National Athletic Trainers' Association, Inc
www.nata.org/jat

Effects of High-Top and Low-Top Shoes on Ankle Inversion

Mark D. Ricard, PhD*; Shane S. Schulties, PhD, PT, ATC*; Jose J. Saret, MS, ATC†

* Brigham Young University, Provo, UT; † Quezon City, Philippines

Objective: To determine the differences in the rate and amount of ankle inversion in subjects wearing high-top and low-top shoes.

Design and Setting: Subjects were filmed at 60 Hz while on an inversion platform that suddenly inverted the right ankle 35°. We measured 5 trials of sudden inversion for each subject in high-top and low-top shoes.

Subjects: Twenty male subjects with no history of lower leg injury within the previous 6 months.

Measurements: We measured ankle inversion using video motion analysis techniques at 60 Hz. A 2 × 5 factorial repeated-measures analysis of variance was used to test for significant differences in the amount of inversion, average rate of inversion, and maximum rate of inversion.

Results: The high-top shoes significantly reduced the amount and rate of inversion. The high-top shoes reduced the amount of inversion by 4.5°, the maximum rate of inversion by 100.1°/s, and the average rate of inversion by 73.0°/s.

Conclusions: The high-top shoes were more effective in reducing the amount and rate of inversion than the low-top shoes. Depending upon the loading conditions, high-top shoes may help prevent some ankle sprains.

Key Words: shoe design, inversion, ankle injury, ligament

An extremely high rate of ankle injury among athletes has been extensively documented in the literature.[1–6] Ankle injuries account for at least 20% to 25% of all time loss in sports involving running and jumping, including basketball, football, soccer, and volleyball.[3,5,7] Ankle injuries are common in sports that involve high-impact loads, which may destabilize the ankle. Because the anatomical structure of the ankle predisposes the lateral ligaments to injury, numerous measures have been advocated for enhancement of dynamic ankle stability. Ankle tape[8] and braces[9,10] have been shown to reduce the amount and rate of ankle inversion. Wearing specially designed footwear, such as high-top shoes, has been suggested to decrease the potential for ankle injury.[11,12]

High-top athletic shoes are frequently chosen to augment ankle support because they may provide increased resistance to ankle inversion.[11] The increased cost of these shoes may be justified if they decrease ankle injury rates.[13] Not all studies, however, support the finding that high-top shoes may reduce the potential for injury. Currently, consensus is lacking among researchers and clinicians concerning the extent to which high-top shoes protect the ankle from inversion trauma.[11–14] The purpose of our study was to determine whether there is a difference in the amount and rate of inversion in subjects wearing high-top and low-top shoes.

METHODS

Subjects

The subjects were 20 male physical education students (age = 20.5 ± 3.47 years, ht = 178.94 ± 5.36 cm, weight = 74.62 ± 9.73 kg) who volunteered for the study. The subjects had, within the previous 6 months, no history of lower leg injury that limited activity for more than 2 days. Subjects were not permitted to participate if they exhibited any of the following: lower extremity nervous impairment, previous fractures or surgery of either ankle, or a positive ankle anterior drawer test.[15] Before participating in the study, each subject read and signed a consent form approved by the Brigham Young University Institutional Review Board.

Materials and Instrumentation

We used an inversion platform with a foot-support base that rotated 35° after a trap door was pulled out with a string to induce sudden ankle inversion (Figures 1 and 2). The platform base is parallel to the ground, and the subjects were tested with a neutral plantar flexion-dorsiflexion angle. The design and function of the platform are similar to those of platforms used in several other studies.[6,9,16,17] A Panasonic AG-450 shuttered video camera (Matsushita Electric Corporation of America, Secaucus, NJ) with the shutter speed set at 1/500 of a second was positioned approximately 4.5 m behind the subject and 60 cm off the ground. This camera was used to record motion in the frontal plane at 60 frames/s. We conducted a pilot test to verify that the shutter speed of 1/500 of a second and sampling rate of 60 Hz were adequate to avoid blurring of the motion and to provide a sufficient number of frames to quantify the amount and rate of inversion.

Address correspondence to Mark D. Ricard, PhD, Physical Education Department, PO Box 22116, Human Performance Research Center, Brigham Young University, Provo, UT 84602-2116. E-mail address: Mark_Ricard@BYU.EDU

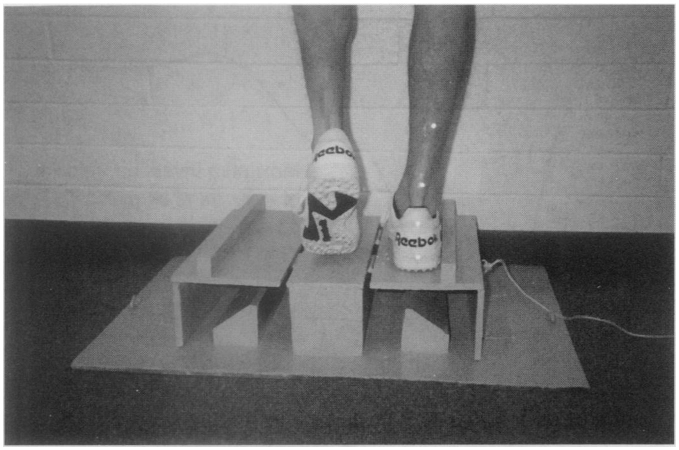

Figure 1. Inversion platform with the subject's weight placed on the right foot and using the toes of the left foot to maintain balance. One-half-centimeter reflective markers were placed on the rear of the lower leg and the rear of the shoe and digitized to measure the ankle inversion response caused by dropping the inversion-platform foot-support base. When the trap door is pulled out with the string, the platform foot-support base rotates 35°, causing a sudden ankle inversion.

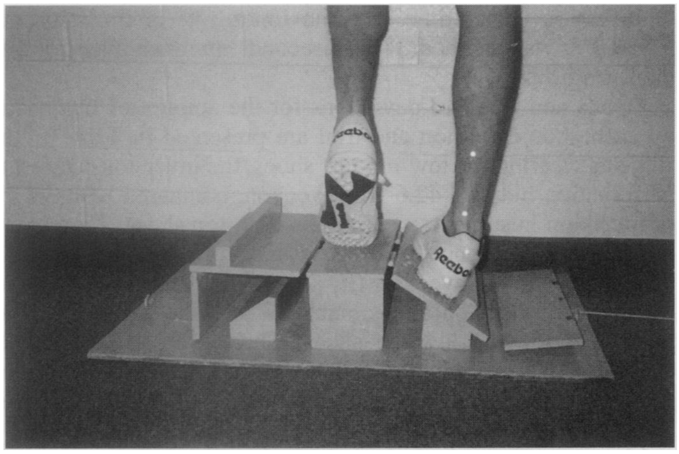

Figure 2. Inversion platform and subject after the trap door was released. The platform foot-support base rotates 35°, causing a sudden ankle inversion.

Testing Protocol

The amount and rate of inversion after an unexpected inversion were measured in subjects wearing high-top and low-top shoes. To minimize the effects of foot movement within the shoe during inversion testing, subjects were instructed to tightly lace their shoes before each set of platform-inversion tests. The order of treatments was counterbalanced to control for possible order effects: odd-numbered subjects were tested with the low-top shoes first, and even-numbered subjects were tested with the high-top shoes first. One-half-centimeter reflective tape markers (Figures 1 and 2) were placed on the rear of the shoe in the center of the heel cup at the intersection of upper and mid sole and 4 cm above the midsole upper intersection.[18] The leg markers were placed at the center of the posterior aspect of the lower leg, 4 cm and 8 cm above the superior edge of the lateral malleolus. These reflective markers were used to detect inversion-eversion of the calcaneus relative to the lower leg when the subject was dropped into inversion.

The subjects were positioned on the inversion platform with the lateral border of the right foot touching the side bar on the platform. They were then instructed to put all their weight on the right foot, using the toes of the left foot to maintain balance and to keep all of their weight on the right foot before and after the inversion platform dropped (Figures 1 and 2). Each subject was given as many test drops as needed to become accustomed with the procedure. The subjects were instructed to look straight ahead while being tested to prevent muscle guarding. At random intervals, the platform door was dropped. The subject was instructed to relax the ankle and roll into the subsequent inversion. Each trial was visually inspected to assure that the subject kept the weight on the right foot and maintained balance throughout the drop of the inversion-platform base. Trials in which the subject was unable to maintain balance or the foot lost contact with the base of the inversion platform were not analyzed. Five trials of sudden inversion were recorded and analyzed for each shoe condition.

Shoe Design

Reebok Turf Rat Hi and Reebok Turf Rat Lo football shoes (Reebok International LTD, Stoughton, MA) were used in this study (Figure 3). The design of the Turf Rat upper is comparable with the upper in basketball shoes, except that the outer sole has several pebble protrusions to optimize friction on an artificial playing surface.

Data Processing and Analysis

An Ariel Video Analysis system (Ariel Dynamics, Inc, San Diego, CA) was used to analyze all video sequences. The Ariel hardware included a 486 AST computer and a Panasonic AG-6750A VCR. Ariel Performance Analysis Software, version 6.5, was used for grabbing the frames and digitizing. The Ariel video analysis system has been found in a previous study[19] to be accurate to less than 3 mm for 3-dimensional measurements and less than 0.3° for angular measurements. Five trials per subject for each condition (high-top and low-top shoes) were digitized. Digitizing was started 5 frames before the platform dropped and continued for 35 frames after the initiation of platform drop.

Rearfoot angles[18] from the raw x and y coordinates of the 4 landmarks (gastrocnemius muscle, Achilles tendon, and top

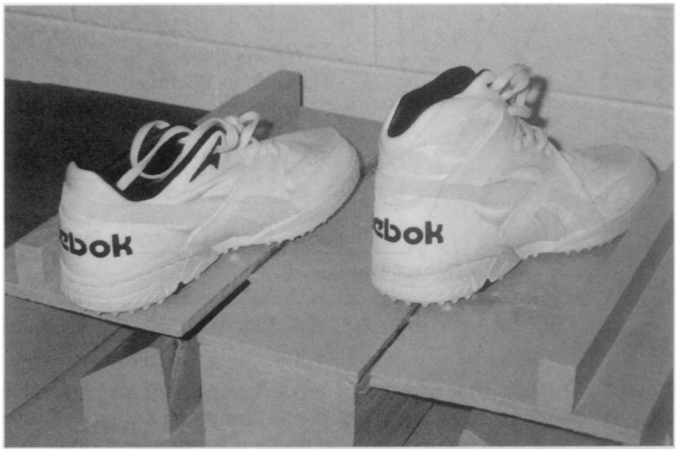

Figure 3. Reebok Turf Rat Hi and Reebok Turf Rat Lo football shoes were used in this study.

and bottom of the shoe) were calculated and smoothed using a Butterworth second-order, recursive digital filter with a cutoff frequency of 10 Hz.[20] We calculated the inversion-eversion angles by subtracting the angle of the rear of the shoe to the right horizontal from the angle of the lower leg to the right horizontal. Inversion was represented by positive angles, and eversion was represented by negative angles.

The amount of inversion was the difference between the initial inversion-eversion angle (when the subject was balanced on the inversion platform) and the maximum inversion angle attained before reversal in the direction of ankle motion after platform drop (Figure 4). The average rate of inversion was calculated by dividing the amount of inversion by the time to maximum inversion. The first central difference formula[20] was used to calculate the instantaneous rate of inversion: rate of inversion (frame) = [(inversion angle in frame 1) − (inversion angle in frame −1)]/Δtime.

The maximum rate of inversion was defined as the maximum inversion velocity attained between the drop of the platform and the point of maximum inversion (Figure 5).

Statistical Analysis

A 2 × 5 factorial, repeated-measures analysis of variance was used to test for significant differences ($P < .05$) in the amount of inversion, average rate of inversion, and maximum rate of inversion. The within-subjects factor, shoe, consisted of 2 levels (high top and low top). The within-subjects factor, trials, consisted of 5 levels. The α level was set at 0.05 for all comparisons. The Bonferroni correction was used to control for experiment-wide error. The Tukey test was used for all post hoc comparisons.

RESULTS

A typical ankle inversion response after the drop of the inversion-platform base is shown in Figure 4. The inversion platform foot-support base rotates 35° in 60 milliseconds; after the platform stops, the ankle joint continues to invert due to the inertia of the center of mass. In the trial shown, the total inversion of 35.3° was attained 117 milliseconds after the initiation of platform drop. The average rate of inversion for this trial was 301.7°/s. Figure 5 depicts a typical trial of the rate of inversion versus time. The maximum rate of inversion of −590.0°/s was attained 34 milliseconds after the initiation of platform drop.

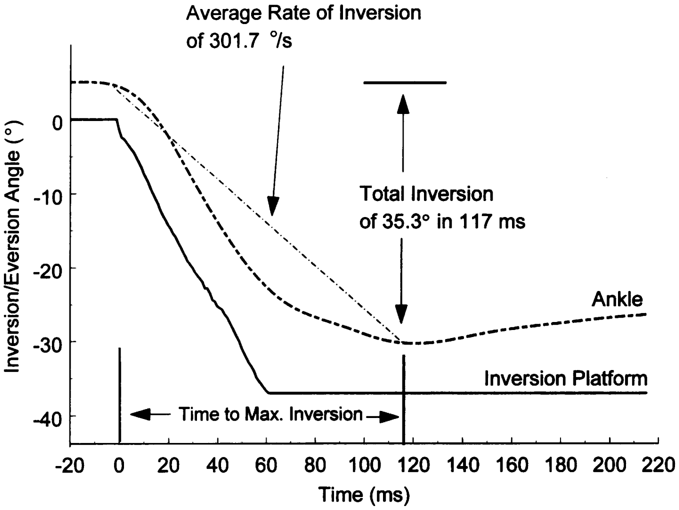

Figure 4. Typical trial of sudden ankle inversion. Total inversion was defined as the difference between the initial ankle inversion angle and the final ankle inversion angle after platform drop. The average rate of inversion was calculated by dividing the amount of inversion by the time to maximum inversion.

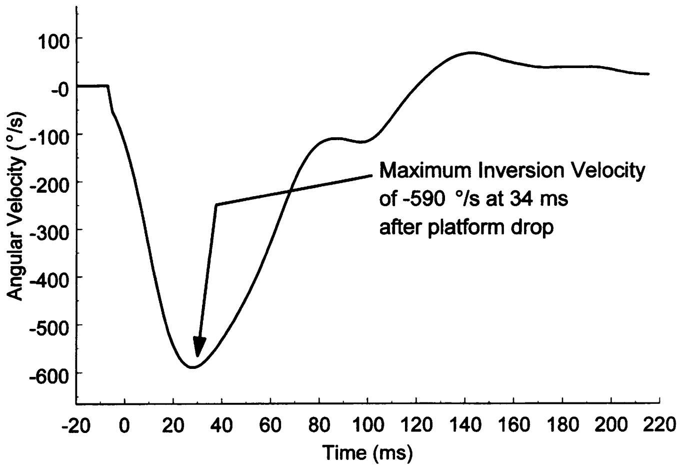

Figure 5. Typical trial of the rate of inversion versus time. The maximum rate of inversion in this trial was −590.0°/s, and it occurred 34 milliseconds after the initiation of platform drop.

Means and standard deviations for the amount of inversion by each shoe condition and trial are presented in Table 1. In subjects wearing the low-top turf shoes, the inversion-platform perturbation induced 42.6° of inversion, compared with 38.1° of inversion in subjects wearing the high-top shoes. There was a significant difference between the high-top and low-top shoes in the amount of inversion ($F_{1,19} = 41.5$, $P < .001$). When wearing the high-top shoes, subjects inverted 4.5° less than when wearing the low-top shoes. There was no significant trial-by-shoe interaction ($F_{4,76} = 0.47$, $P = .76$) and no significant difference between trials ($F_{4,76} = 0.41$, $P = .81$) in the amount of inversion.

Means and standard deviations for the average rate of inversion by each shoe condition and trial are presented in Table 2. We observed a significant shoe effect for the average rate of inversion ($F_{1,19} = 103.0$, $P < .001$). The high-top shoes reduced the average rate of inversion by 73.0°/s when compared with the low-top shoes. There was no significant trial-by-shoe interaction ($F_{4,76} = 1.35$, $P = .26$) and no significant difference between trials ($F_{4,76} = 0.37$, $P = .83$) in the average rate of inversion.

Means and standard deviations for the maximum rate of inversion by each shoe condition and trial are presented in Table 3. A significant shoe effect for the maximum rate of inversion was observed ($F_{1,19} = 46.8$, $P < .001$). The high-top

Table 1. Amount of Inversion (°) by Shoe Condition (Mean ± SD)

Trial	High-Top Shoes	Low-Top Shoes
1	37.7 ± 4.2	42.5 ± 3.6
2	38.7 ± 3.7	42.5 ± 3.6
3	38.5 ± 2.2	42.8 ± 4.8
4	37.5 ± 3.2	42.8 ± 4.2
5	38.0 ± 3.7	42.6 ± 4.9
5-trial mean	38.1 ± 2.5*	42.6 ± 3.7*

*Means are significantly different ($P < .001$).

Table 2. Average Rate of Inversion (°/s) by Shoe Condition (Mean ± SD)

Trial	High-Top Shoes	Low-Top Shoes
1	309.3 ± 46.4	371.2 ± 46.4
2	316.4 ± 35.1	373.6 ± 41.0
3	299.2 ± 30.9	382.2 ± 42.9
4	293.8 ± 42.0	381.4 ± 43.8
5	307.5 ± 35.5	382.2 ± 52.0
5-trial mean	305.2 ± 19.7*	378.2 ± 33.2*

*Means are significantly different ($P < .001$).

Table 3. Maximum Rate of Inversion (°/s) by Shoe Condition (Mean ± SD)

Trial	High-Top Shoes	Low-Top Shoes
1	384.8 ± 73.2	508.6 ± 104.2
2	400.8 ± 71.9	517.4 ± 91.5
3	422.6 ± 64.0	508.1 ± 98.5
4	417.3 ± 86.1	505.6 ± 96.8
5	423.8 ± 67.2	509.8 ± 95.8
5-trial mean	409.8 ± 59.3*	509.9 ± 90.9*

*Means are significantly different ($P < .001$).

shoes reduced the maximum rate of inversion by 100.1°/s when compared with the low-top shoes. There was no significant trial-by-shoe interaction ($F_{4,76} = 1.29$, $P = .28$) and no significant difference between trials ($F_{4,76} = 1.92$, $P = .12$) in the maximum rate of inversion.

DISCUSSION

Most ankle sprains are caused by stepping or landing on an unexpected object underneath the medial side of the foot. The magnitude of muscular activation about the ankle joint is preprogrammed. Based upon previous experience, the ankle musculature is preactivated to provide initial joint stiffness before ground contact in running,[8,21] landing,[22] and cutting.[23] If an athlete wishes to minimize the potential for an ankle sprain, he or she could simply maximally activate the ankle joint muscles before ground contact. While this increased muscular stiffness would protect the ankle from most inversion injuries, it is extremely inefficient and would result in rapid fatigue of the ankle joint muscles. The neuromuscular system optimizes the system for efficiency rather than optimizing the protection of the ankle from injury, and, as a result, the muscular activation of the ankle joint is modulated to provide ankle joint stiffness to protect the joint only from typically imposed forces. After each step, the results of previous contacts with the ground are evaluated, and the level of muscular activation is then readjusted as needed. Since the neuromuscular system does not prepare the body for an unexpected event like landing on a rock, the initial ankle inversion stiffness at ground contact is very low, and the rock causes a rapid and possibly injurious inversion about the ankle joint. Depending upon the rate and magnitude of loading, the minimum time for the neuromuscular system to perceive the unexpected object and generate a protective muscular response is about 120 milliseconds.[6,24] It has often been suggested that the ankle evertors can protect the ankle joint from inversion-induced trauma.[25–29] However, there are 2 reasons why the peroneals provide only limited protection from an inversion injury. First, before ground contact, the evertors are minimally preactivated,[8,21,30] resulting in very little initial resistance to inversion; the peroneals require approximately 120 milliseconds to develop tension in an attempt to increase ankle joint stiffness.[6,24] Second, most ankle sprains are the result of the body's center of mass being laterally displaced in relation to the vertical component of the ground reaction force, producing a force couple that generates a far greater magnitude of torque than the maximum that can be effectively resisted by the peroneal muscles.[28–32] The potential for ligamentous injury to the ankle is high whenever the rate and magnitude of ankle loading exceed the response time for the neuromuscular system. It, therefore, is paramount that some type of force bypass, such as taping,[16,17,32] bracing,[9,32,33] or wearing high-top shoes,[11,12,32,34] or a combination of these, be used in situations in which there is a high potential for injury.

High-top shoes provide increased resistance to ankle rotation,[11,12,32] which may protect athletes from ankle sprains. The results of previous investigations into the additional inversion protection provided by high-top shoes over low-top shoes have been inconsistent.[4,11–13,33] Barrett and Bilisko[35] found no significant difference in injury rates between players wearing high-top and low-top shoes. However, most comparisons between high-top and low-top shoes have shown that high-top shoes do significantly reduce inversion. Shapiro et al[11] demonstrated a significant increase in passive ankle resistance to inversion moments when a high-top shoe was worn. Ottaviani et al[12] found that subjects could generate 29.4% greater resistance to ankle inversion with a firmly laced three-quarter-top shoe than with a low-top shoe. High-top shoes were found to significantly reduce inversion in lateral cutting movements in tennis when compared with low-top shoes.[36,37] In a later study of lateral cutting movements in floor hockey, Stacoff et al[38] observed that high-top shoes significantly improved lateral stability in cutting movements, reducing the amount of inversion by approximately 6°. Avramakis et al,[39] in a similar study of cutting movements in floor hockey, found that high-top shoes reduced the amount of inversion by 13.8° in forward-sideward cutting movements and by 10.4° in lateral cutting movements when compared with low-top shoes.

Garrick and Requa[13] surveyed 2562 basketball player-games and demonstrated that the lowest ankle injury rates were among players with high-top shoes and taped ankles, with 6.5 sprains per 1000 player-games. The highest rate of injury was among players with low-top shoes and no tape: 33.4 sprains per 1000 player-games. Our investigation showed that the subjects decreased their amount of inversion by 4.5° when wearing a high-top shoe as compared with a low-top shoe. When compared with the low-top shoes, the high-top shoes reduced the average rate of inversion by 73.0°/s and the maximum rate of inversion by 100.1°/s. Vaes et al[10] suggested that slowing down the rate of inversion may create more time for muscular protection of the ankle joint. The importance of reducing the rate of inversion was further clarified by Wilkerson and Nitz,[40] who suggested that the torque about the weightbearing ankle joint increases markedly as the foot moves from neutral to maximum inversion. We believe that a reduction in the amount and rate of inversion may allow the body's protective mechanisms time to respond and, depending upon the conditions of loading, may reduce the potential for ankle sprain. The relative importance of the loading rate upon ankle sprains can be illustrated with a simple example. Most individuals have experienced a "near-sprain event," in which they stepped on the edge of a curb or a rock on the medial side of the shoe, and the ankle subsequently inverted. When the rate of loading is slow, the body has sufficient time to react, thus preventing the injury. When the rate of loading is fast, the body does not have sufficient time to react, resulting in an inversion injury.

The biomechanical factors that determine the relative potential of a load to cause an ankle sprain include the magnitude of force, the rate of application, the point of application, the direction of force application, the critical state of the tissues (bone, ligament, tendon, muscle), the preactivation of the muscles, and the design characteristics of the shoe. Our results suggest that the high-top shoes reduce the amount and rate of ankle inversion; however, this does not ensure that the high-top shoes will prevent ankle sprains. It is well known that athletes sprain their ankles when wearing high-top shoes. Garrick and Requa[13] observed 30.4 sprains per 1000 player-games in athletes wearing high-top shoes. Yet it is difficult to compare shoe studies due to the multitude of advancements in shoe design in recent years. The design characteristics of the shoe can significantly influence the mechanical function of the shoe. Altering the torsional stiffness of the shoe upper[41,42] or midsole geometry[43,44] has been shown to augment the inversion protection offered by the shoe.

Despite the limited protective ability of the peroneals, we believe that peroneal strengthening or proprioceptive training, or both, are necessary, particularly for rehabilitation purposes after an ankle injury.[27,40,45,46] Strength and proprioceptive training may help reduce the potential for injury when the rate and magnitude of loading are low enough to allow the neuromuscular system sufficient time to respond.

Future studies are needed to investigate possible additive effects of force bypass methods, such as high-top shoes with ankle taping or ankle bracing, on the amount and rate of ankle inversion. In addition, our results depend upon the type of shoes tested and the amount of inversion-platform rotation. Changes in shoe or inversion-platform characteristics may produce different results.

CONCLUSIONS

High-top shoes reduced the amount of inversion by 4.5°, the maximum rate of inversion by 100.1°/s, and the average rate of inversion by 73.0°/s when compared with low-top shoes. Depending upon the loading conditions, subjects wearing high-top shoes may reduce their risk of ankle sprains.

REFERENCES

1. Lentell G, Baas B, Lopez D, McGuire L, Sarrels M, Snyder P. The contributions of proprioceptive deficits, muscle function, and anatomic laxity to functional instability of the ankle. *J Orthop Sports Phys Ther.* 1995;21:206–215.
2. Balduini FC, Tetzlaff J. Historical perspectives on injuries of the ligaments of the ankle. *Clin Sports Med.* 1982;1:3–12.
3. Garrick JG. The frequency of injury, mechanism of injury, and epidemiology of ankle sprains. *Am J Sports Med.* 1977;5:241–242.
4. Lassiter TE Jr, Malone TR, Garrett WE Jr. Injury to the lateral ligaments of the ankle. *Orthop Clin North Am.* 1989;20:629–640.
5. Mack RP. Ankle injuries in athletics. *Clin Sports Med.* 1982;1:71–84.
6. Konradsen L, Voigt M, Hojsgaard C. Ankle inversion injuries: the role of the dynamic defense mechanism. *Am J Sports Med.* 1997;25:54–58.
7. Jackson DW, Ashley RL, Powell JW. Ankle sprains in young athletes: relation of severity and disability. *Clin Orthop.* 1974;101:201–215.
8. Ricard MD, Schulthies SS, Brinton M, Tricoli VA, Han KM. The role of the evertors in sudden inversion and gait. In: Arsenault AB, McKinley P, McFayden B, eds. *Proceedings of the Twelfth International Society of Electrophysiology and Kinesiology Congress.* Montreal, Quebec, Canada: International Society of Electrophysiology and Kinesiology; 1998:248–249.
9. Podzielny S, Hennig EM. Restriction of foot supination by ankle braces in sudden fall situations. *Clin Biomech.* 1997;12:253–258.
10. Vaes PH, Duquet W, Casteleyn PP, Handelberg F, Opdecam P. Static and dynamic roentgenographic analysis of ankle stability in braced and nonbraced stable and functionally unstable ankles. *Am J Sports Med.* 1998;26:692–702.
11. Shapiro MS, Kabo JM, Mitchell PW, Loren G, Tsenter M. Ankle sprain prophylaxis: an analysis of the stabilizing effects of braces and tape. *Am J Sports Med.* 1994;22:78–82.
12. Ottaviani RA, Ashton-Miller JA, Kotharie SU, Wojtys EM. Basketball shoe height and the maximal muscular resistance to applied ankle inversion and eversion moments. *Am J Sports Med.* 1995;23:418–423.
13. Garrick JG, Requa RK. Role of external support in the prevention of ankle sprains. *Med Sci Sports.* 1973;5:200–203.
14. Karlsson J, Andreasson GO. The effect of external ankle support in chronic lateral ankle joint instability: an electromyographic study. *Am J Sports Med.* 1992;20:257–261.
15. Magee DJ. *Orthopedic Physical Assessment.* Philadelphia, PA: WB Saunders; 1987:480.
16. Ricard MD, Sherwood SM, Schulthies SS, Knight KL. Effects of tape and exercise on dynamic ankle inversion. *J Athl Train.* 2000;35:31–37.
17. Pederson TS, Ricard MD, Merrill G, Schulthies SS, Allsen PE. The effects of spatting and ankle taping on inversion before and after exercise. *J Athl Train.* 1997;32:29–33.
18. Clarke TE, Frederick EC, Hamill CL. The study of rearfoot movement in running. In: Frederick EC, ed. *Sport Shoes and Playing Surfaces.* Champaign, IL: Human Kinetics; 1984:166–189.
19. Klein PJ, DeHaven JJ. Accuracy of three-dimensional linear and angular estimates obtained with the Ariel performance analysis system. *Arch Phys Med Rehabil.* 1995;76:183–189.
20. Winter DA. *Biomechanics and Motor Control of Human Movement.* New York, NY: John Wiley & Sons; 1990:27–48.
21. Reber L, Perry J, Pink M. Muscular control of the ankle in running. *Am J Sports Med.* 1993;21:805–810.
22. Komi PV, Gollhofer A. Stretch reflexes can have an important role in force enhancement during SSC exercise. *J Appl Biomech.* 1997;13:451–460.
23. Neptune RR, Wright IC, van den Bogert AJ. Muscle coordination and function during cutting movements. *Med Sci Sports Exerc.* 1999;31:294–302.
24. Enoka RM. *Neuromechanical Basis of Kinesiology.* Champaign, IL: Human Kinetics; 1990:250.
25. Brunt D, Andersen JC, Huntsman B, Reinhert LB, Thorell AC, Sterling JC. Postural responses to lateral perturbation in healthy subjects and ankle sprain patients. *Med Sci Sports Exerc.* 1992;24:171–176.
26. Sheth P, Yu B, Laskowski ER, An KN. Ankle disk training influences reaction times of selected muscles in a simulated ankle sprain. *Am J Sports Med.* 1997;25:538–543.
27. Ebig M, Lephart SM, Burdett RG, Miller MC, Pincivero DM. The effect of sudden inversion stress on EMG activity of the peroneal and tibialis anterior muscles in the chronically unstable ankle. *J Orthop Sports Phys Ther.* 1997;26:73–77.
28. Tropp H. Pronator muscle weakness in functional instability of the ankle joint. *Int J Sports Med.* 1986;7:291–294.
29. Wilkerson GB, Pinerola JJ, Caturano RW. Invertor vs. evertor peak torque and power deficiencies associated with lateral ankle ligament injury. *J Orthop Sports Phys Ther.* 1997;26:78–86.
30. Heitman RJ, Kovaleski J, Gurchiek L. Isokinetic eccentric strength of the ankle evertors after injury. *Percept Mot Skills.* 1997;84:258.
31. Ashton-Miller JA, Ottaviani RA, Hutchinson C, Wojtys EM. What best protects the inverted weightbearing ankle against further inversion? *Am J Sports Med.* 1996;24:800–809.
32. Bruns J, Staerk H. Mechanical ankle stabilization due to the use of orthotic devices and peroneal muscle strength: an experimental investigation. *Int J Sports Med.* 1992;13:611–615.
33. Rovere GD, Clarke TJ, Yates CS, Burley K. Retrospective comparison of

taping and ankle stabilizers in preventing ankle injuries. *Am J Sports Med.* 1988;16:228–233.

34. Johnson GR, Dowson D, Wright V. A biomechanical approach to the design of football boots. *J Biomech.* 1976;9:581–585.
35. Barrett J, Bilisko T. The role of shoes in the prevention of ankle sprains. *Sports Med.* 1995;20:277–280.
36. Stussi A, Stacoff A, Tiegermann V. Rapid sideward movements in tennis. In: Segesser B, Pforringer W, eds. *The Shoe in Sport.* Chicago, IL: Year Book Medical Publishers; 1989:53–62.
37. Stacoff A, Steger J, Stussi E, Reinschmidt C. Lateral stability in sideward cutting movements. *Med Sci Sports Exerc.* 1996;28:350–358.
38. Stacoff A, Avramakis E, Siegenthaler R, Stussi E. High-cut shoes and lateral heel stability during cutting movements in floorball. *J Biomech.* 1998;31:178.
39. Avramakis E, Stacoff A, Stussi E. Shoe design and lateral stability in floorball. Presented at: Fourth International Society of Biomechanics Symposium on Footwear Biomechanics; August 5–7, 1999; Canmore, Alberta, Canada.
40. Wilkerson GB, Nitz AJ. Dynamic ankle stability: mechanical and neuromuscular interrelationships. *J Sport Rehabil.* 1994;3:43–57.
41. Robinson JR, Frederick EC, Cooper LB. Systematic ankle stabilization and the effect on performance. *Med Sci Sports Exerc.* 1986;18:625–628.
42. Stacoff A, Kaelin X, Stuessi E, Segesser B. The torsion of the foot in running. *Int J Sport Biomech.* 1989;5:375–389.
43. Luethi SM, Frederick EC, Hawes MR, Nigg BM. Influence of shoe construction on lower extremity kinematics and load during lateral movements in tennis. *Int J Sport Biomech.* 1986;2:166–174.
44. Barnes RA, Smith PD. The role of footwear in minimizing lower limb injury. *J Sports Sci.* 1994;12:341–353.
45. Konradsen L, Olesen S, Hansen HM. Ankle sensorimotor control and eversion strength after acute ankle inversion injuries. *Am J Sports Med.* 1998;26:72–77.
46. Lephart SM, Pincivero DM, Giraldo JL, Fu FH. The role of proprioception in the management and rehabilitation of athletic injuries. *Am J Sports Med.* 1997;25:130–137.