Prophylactic ankle stabilizers affect ankle joint kinematics during drop landings

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ABSTRACT
McCRAW, S. T. and J. F. CERULLO Prophylactic ankle stabilizers affect ankle joint kinematics during drop landings. Med. Sci. Sports Exerc., Vol. 31, No. 5, pp. 702–707, 1999. Purpose: Ankle joint dorsiflexion contributes to energy absorption during landing, but wearing ankle stabilizers is known to restrict passive measures of dorsiflexion. This study compared the effects of various ankle stabilizers on ankle joint kinematics during soft and stiff landings. Methods: Subjects (N = 14) performed two-legged landings off a 0.59-m platform. Kinematics of the right ankle were calculated from a sagittal plane video recording (120 Hz). Five soft and five stiff landings were performed in five ankle stabilizer conditions (no stabilizer, taping, Swede-O, AirCast, and Active Ankle), a total of 50 trials per subject. Style and stabilizer conditions were randomized across subjects. Each subject’s five-trial mean value of selected kinematic variables for each landing style/stabilizer condition was entered into a two-way repeated MANOVA (α = 0.05). Results: Differences between soft and stiff landing conditions were similar to those reported in the literature. Compared with the No stabilizer condition, most stabilizer conditions significantly reduced ankle dorsiflexion ROM and angular velocity during landing. Conclusions: The results indicate that some ankle stabilizers adversely affect ankle joint kinematics during landing. Key Words: TAPING, BRACES, ORTHOTICS, ROM, SHOCK ABSORPTION

A common mechanism of ankle ligament injury is an applied inversion stress while the ankle is in a plantarflexed position. Such loading may damage the lateral structures of the joint, specifically the anterior talofibular and calcaneofibular ligaments (2). To decrease the risk of an inversion sprain, traditional ankle taping or various commercially available ankle stabilizers have been used to provide functional stabilization to the joint (1,13,14,17,23). Although the mechanism of prophylaxis with ankle stabilization is not clear (11,17), epidemiological evidence suggests the use of ankle stabilizers is cost effective for reducing the frequency of ankle injuries (6,13,18,21).

A restriction of inversion and eversion ranges of motion (ROM) with ankle stabilization has been reported in several studies (3,16,22,23). After several minutes of activity, the measured ankle joint ROM approaches the ROM measured in a nonstabilized condition (7–9,16). Authors typically interpret the results as indicative of a loss of support from the stabilizer (16) and suggest that loosened stabilizers are ineffective for protecting the joint. However, over 20 years ago Garrick and Requa (6) proposed that an ideal stabilizer would not impinge on the usual ROM of the ankle joint. Restriction should occur only at the anatomical limits of joint motion, the position beyond which joint capsule or ligament damage begins to occur. This concept of the ideal brace recognizes the importance of an unimpeded ankle joint ROM to the generation and absorption of energy during skill performance. Several studies have demonstrated the importance of eccentrically controlled ankle dorsiflexion to energy absorption during landing (4,5,10). DeVita and Skelly (4) reported alterations in the relative contribution of the ankle, knee, and hip joints to energy absorption between soft and stiff landings. In soft landings the hip, knee, and ankle joints contributed 25, 37, and 37%, respectively, to the total energy absorbed by the lower extremity. During stiff landings, in addition to less total energy absorption by the lower limb, the relative contributions of the hip, knee, and ankle joints were altered to 20, 31, and 50%, respectively, of the total energy absorbed. As landing stiffness increased, the posterior ankle musculature contributed more to relative energy absorption while the contribution of the posterior hip and anterior knee musculature decreased.

Practitioners recognize the importance of unimpeded hip; knee, and ankle flexion to shock absorption. Kareem Abdul
Jabbar attributed his long career in the National Basketball Association to the use of low cut basketball shoes, stating (19), p. 90: “Your skeletal system was built to absorb shock. If you bind your ankles, the stress is going to get transferred to the next available joint—your knee.”

In spite of the acknowledged importance of the ankle to energy absorption, quantification of an altered contribution to energy absorption during conscious restrictions of ankle motion, widespread use of prophylactic ankle stabilizers, and the reported impingements of ankle joint range of motion when wearing ankle stabilizers, no published studies compare ankle kinematics during landing with different conditions of ankle stabilization. The purpose of this study was to compare the effects of landing style and ankle stabilizers on ankle joint kinematics during landing. The ankle joint kinematic variables quantified were (a) angular displacement (plantarflexion and dorsiflexion) and (b) angular velocity.

METHODS

Subjects. Fourteen college students (five female: age, 20 ± 1 yr; height, 1.66 ± 0.05 m; mass, 60 ± 5 kg; and nine male: age, 21 ± 2 yr; height, 1.77 ± 0.07 m; mass, 83 ± 16 kg) volunteered as subjects. As determined by a questionnaire, all subjects were experienced in landing (history of participation in basketball or volleyball) and free of any acute or chronic injuries for 1 yr before data collection. Before participating, all subjects read and signed an informed consent form in accordance with the policy statements of ACSM and approved by the Institutional Review Board of the University.

Ankle stabilization. In addition to the condition with no stabilizer, data were collected from four ankle stabilized conditions, including tape and three commercially available stabilizers. Manufacturers provided the stabilizers in different sizes. Stabilizers were applied to both ankles of each subject by the same certified athletic trainer according to recommendations of the manufacturer. Details of each stabilized condition are described below.

For the tape condition, the shaved foot and ankle were sprayed with a tape adherent (Cramer Tuffskin, Gardner, KS) and wrapped with a foam prewrap. Gel-lubed heel and lace gauze pads were applied before ankle taping. The certified athletic trainer applied bleached white tape (Coach Athletic Tape, Johnson & Johnson, Skillman, NJ) using a modified Gibney closed basketwork weave, with two heel locks and two figures-of-eight (2).

Stabilizer 1 was a lace-up, boot style stabilizer (Swede-O-Universal, North Branch, MN) recommended as a cost reducing alternative to taping of the ankle joint. The stabilizer was included in the study because it covers the medial/lateral and anterior/posterior surfaces of the ankle joint from above the malleoli to the base of the metatarsals, similar to ankle taping.

Stabilizers 2 and 3 consisted of two semirigid plastic outer shells hinged to a plastic stirrup at the malleoli. The stabilizers are held in place by two self-stick straps spaced approximately 0.02 m apart encircling the distal shank superior to the malleoli. Stabilizer 2 was lined with inflatable air cells (Aircast Sport Stirrup, Summit, NJ) while stabilizer 3 was lined with foam (Cramer Active Ankle, Gardner, KS). These stabilizers were included in the study because they both provide medial and lateral support while leaving open the anterior and posterior surfaces of the ankle joint, making them mechanically different from tape and stabilizer 1.

Experimental protocol. Before the actual data collection, each subject was fitted with a pair of standard low cut laboratory running shoes and practiced both soft and stiff landings from the required height.

Collection of landing data used a technique similar to that of DeVita and Skelly (4). To control vertical speed to approximately 11.6 m s⁻¹ at landing, subjects stepped off a 0.59 m high wooden platform placed 0.11 m behind the back edge of the landing target. The take-off technique was controlled by having each subject assume a position on the top step of the platform with both arms flexed to shoulder height and the heel of the right foot resting against the front edge of the platform. The subject then leaned forward to step off the platform. The technique allowed the subject to minimize horizontal motion and land equally balanced on both feet, with the right foot closest to the video camera. Subjects were instructed to land with maximum knee flexion during soft landings and minimum knee flexion during stiff landings.

Five landing trials of each subject were recorded within each of the 10 landing conditions (two landing styles (soft and stiff) and five stabilized conditions (nonstabilized, taped, Stabilizer 1 (Swede-O), Stabilizer 2 (AirCast), Stabilizer 3 (Active Ankle)). All conditions were performed during a single test session of approximately 3 h duration. Ankle stabilized conditions were randomized across all subjects, and landing style was randomized within each ankle stabilized condition. To maximize any effect of ankle stabilization, landings were performed immediately after application of the orthotic.

Video recording. A sagittal plane recording was made of each landing trial in each condition using a high speed (120 Hz) video system (Peak Performance Technologies Inc., Englewood, CO). The camera was set at a height of 0.8 m and positioned approximately 7.0 m from the landing area to provide a sagittal plane field of view approximately 1.5 m wide and 2.2 m high.

To track and digitize anatomical landmarks defining the foot and shank of the right lower extremity, reflective tape markers approximately 2 cm in diameter were placed on: a) the lateral shoe upper at the base of the fifth metatarsal; b) the lateral heel of the shoe just superior to the seam between the sole and heel cup; c) the lateral malleolus; and d) the knee joint center. After fitting for each stabilizer condition, the lateral malleolus was carefully palpated and the marker replaced over the stabilizer.

The ankle was defined (Fig. 1) as the relative angle between the foot (heel and fifth metatarsal) and the shank (lateral malleolus and knee joint center). The two segments did not share a common vertex. The Peak5 software was
Plantarflexion

Figure 1—Convention used to measure ankle joint position.

used to calculate the ankle angle, with plantarflexion and dorsiflexion measured in degrees from the anatomical (0°) position.

Digitization. Following time-coding of the video tape, the four anatomical landmarks were automatically digitized (Peak5 Performance Technologies Inc., Video and Analog Motion Measurement Systems Software Version 5.3). Digitizing began 20 fields before initial toe contact (touch down), a period including the last 0.1 s of the descent phase, plus eight extra fields. Successive fields were digitized until at least 16 fields following observed maximum knee flexion, the end of the shock absorption phase. Additional fields were digitized to improve the accuracy of data smoothing with a digital filter. The x and y coordinate data of each landmark were smoothed using the optimized Butterworth Filter option of the Peak5 software. The cut-off frequencies, determined using the Jackson “knee” method (12) with the preferred level set at 0.1, varied within the range of 5 to 9 Hz.

Representative curves for soft and stiff landings are presented in Figure 2. The dependent variables defining ankle joint kinematics included joint angle at touch down (degrees plantarflexion), angle at maximum knee flexion (degrees dorsiflexion), ankle joint ROM (degrees), maximum ankle angular velocity (degrees per second), and time to maximum ankle angular velocity (s).

Statistics. For each subject, a five-trial mean value of each dependent variable was calculated for each of the 10 landing styles by stabilizer conditions and used in the statistical analysis. The measurement of multiple dependent variables during multiple conditions necessitated the use of a doubly multivariate 2 × 5(landing style by stabilizer) MANOVA (20), with α = 0.05. Since ROM is a linear combination of joint angle at touch down and angle at maximum knee flexion, ROM was not included in the MANOVA. To identify the source of a significant omnibus F-ratio, univariate repeated measure ANOVA were conducted on each dependent variable, including the ROM. When appropriate, the Tukey-b procedure (α = 0.05) was utilized to identify which stabilizer mean values were significantly different. Post-hoc power analyses indicated multivariate power values of 0.61 for the landing style by stabilizer interaction, and 0.89 and 1.00 for style and stabilizer main effects, respectively.

RESULTS

The repeated-measures MANOVA indicated no significant interaction (Wilks λ = 0.68, F = 1.24, P = 0.241), but both style (Wilks λ = 0.29, F = 6.02, P = 0.010) and stabilizer (Wilks λ = 0.20, F = 6.40, P < 0.0005) main effects were identified. Figures 3 to 7 present the descriptive statistics of landing style-stabilizer conditions for each dependent variable in graphic format. The presentation of results will focus only on identified main effects, interpreting the outcome of the univariate repeated measures ANOVA conducted for each independent variable.

Ankle joint angle at touch down. There was no significant landing style effect (F (1,13) = 0.11, P = 0.748), but there was a significant stabilizer effect (F (4,52) = 13.38.
ANKLE STABILIZERS DURING LANDING

The purpose of this study was to compare the effects of landing style and ankle stabilizers on ankle joint kinematics during landing. Different methods of stabilizing the ankle, including commercially available ankle braces, were compared. This study did not investigate the effects of the ankle stabilizers on the prevention of ankle inversion sprains. No evaluations of subject comfort or stabilizer preference were made. As a result, the results should not be interpreted as suggesting that one method of stabilization is preferable to any other method of stabilization. In fact, since the data were collected for this study, each of the manufacturers who donated a model for testing have brought to market new models of the stabilizers.

The results of this study suggest that some prophylactic ankle stabilizing techniques commonly used to prevent inversion sprains impinge on the normal kinematics of the ankle. There were significant main effects of landing style and ankle stabilizers on ankle joint ROM in the Swede-O (32.8 ± 6.6°), Aircast (32.6 ± 5.8°), and tape (32.9 ± 5.2°) conditions compared with the no stabilizer (39.4 ± 7.0°) condition. The maximum ankle angular velocity was lower during each stabilizer condition compared with the nonstabilized condition. The Tukey post-hoc analysis revealed that angular velocity in the Swede-O (526.7 ± 91.5°s⁻¹) and Aircast (517.4 ± 71.7°s⁻¹) conditions was 70–120°s⁻¹ slower than the Active Ankle (590.2 ± 101.3°s⁻¹) and no stabilizer (639.7 ± 95.2°s⁻¹) conditions. Angular velocity in the Active Ankle (590.2 ± 101.3°s⁻¹) and tape (546.6 ± 69.1°s⁻¹) conditions was 50–90°s⁻¹ slower than the no stabilizer condition (639.7 ± 95.2°s⁻¹).

**Time to maximum angular velocity.** There was no significant main effect for either landing style (F(1,13) = 0.17, P = 0.683) or stabilizer (F(4,52) = 1.90, P = 0.125).

**DISCUSSION**
ankle joint during drop landings. Compared with the unsta-
obilized control condition, some stabilizers restricted the
ankle joint range of motion during landing, reflecting a
combination of reduced ankle plantarflexion at contact and
reduced dorsiflexion during the impact phase of ground
contact. The finding of a reduced range of sagittal plane
motion during landing with ankle stabilization is counter to
the report of no effect of stabilization on sagittal plane
motion during running by Lindley and Kernozek (15). How-
ever, the range of motion when running is less than that used
in landing, and any restriction from ankle stabilization may
not interfere with the measured range of motion.

The implication of a reduced ankle range of motion
during landing is that less energy may be absorbed by the
soft tissues controlling the ankle motion, especially the
eccentric action of the posterior ankle musculature. DeVita
and Skelly (4) demonstrated a change in the relative con-
tribution of the ankle, knee, and hip joints to energy absorp-
tion between soft and stiff landing styles. They determined
that the hip, knee, and ankle absorbed 25, 37, and 37%,
respectively, of the total energy absorbed during soft land-
ings. When subjects consciously reduced joint range of
motion to land stiff, the relative contribution of the lower
extremity joints to total energy absorption was changed to
20, 31, and 50% for the hip, knee, and ankle joints, respec-
tively. In the present study, the change from soft to stiff
landings was characterized kinematically by a 5° reduction
in ankle joint range of motion, similar to that presented by
DeVita and Skelly (4). The 5° decrease in dorsiflexion range
of motion from soft to stiff landings is similar to the quan-
tified change between the unstabilized landing condition
and some of the stabilizing techniques used in the current
study, specifically ankle taping and stabilizers 1 and 2. A
subsequent project that arises from the present study is to
quantify whether knee and hip joint kinematics are altered
when ankle stabilizers are used. Of greater importance is to
determine, using an inverse dynamic analysis, whether the
5° decrease in dorsiflexion ROM when landing with ankle
stabilizers is accompanied by alterations in the energy ab-
sorption patterns of the ankle, knee, and hip joints similar to
those reported by DeVita and Skelly (4) for soft and stiff
landings.

Although energy absorption was not measured in this
study, there were measured changes in the maximum angu-
lar velocity of dorsiflexion during landing. For the three
stabilized conditions that exhibited significantly less dorsi-
flexion range of motion than the unstabilized condition, the
maximum dorsiflexion angular velocity was, on average,
about 110°·s⁻¹ less than that in the unstabilized condition. A
reduction in angular velocity could reflect a decrease in
energy absorption based on the work-energy relationship.
Changes in the angular component of kinetic energy of a
body occur when work, in the form of an unbalanced torque
over a range of motion, is done on the body. In landing, the
angular velocity of the joints is reduced to zero at the end of
the descent phase. A higher peak angular velocity reflects a
greater angular kinetic energy of the rotating bodies. Greater
negative work, in the form of a torque applied opposite to
the direction of rotation, must be done to reduce the angular
kinetic energy to zero. The source of the torque to decrease
angular velocity at the ankle is the eccentric activity in the
posterior muscles of the ankle. Thus, it may be hypothesized
that greater eccentric activity was needed to reduce the
higher dorsiflexion angular velocity exhibited during a land-
ing with unstabilized ankles compared with a landing with
stabilized ankles. Since eccentric activity of muscles reflects
absorption of energy (24), greater energy absorption by the
posterior ankle muscles would occur during landings with
ankles unstabilized compared with landings with ankles
stabilized. Conversely, reduced energy absorption by the
ankle musculature while wearing stabilizers would mean
greater energy transfer up the leg, increasing the demand on
knee and hip musculature to absorb energy if the same total
energy is to be absorbed by the lower extremity in stabilized
and unstabilized landings. Support of this interpretation will
require application of an inverse dynamics analysis to mea-
sure the energy absorption during landings with and without
ankle stabilization.

The stabilizing techniques that significantly reduced an-
kle joint range of motion either wrap completely around the
foot/ankle complex (tape and stabilizer 1) or grip the medial
and lateral malleolus in air cells (stabilizer 2). The single
stabilizer tested that did not significantly affect ankle kine-
matics was characterized by a hinge support intended to

Figure 6—Maximum ankle joint angular velocity during the landing
phase.

Figure 7—Time to maximum ankle joint angular velocity during the
landing phase.
provide frontal plane stability while not tightly binding to the malleoli. No measures were made of pressure exerted on the ankle joint by the different stabilizing techniques used, but the manufacturer's guidelines for use of the stabilizers were followed during application. Also, testing was conducted immediately after application of the stabilizing technique, and no activity time, known to cause loosening of the stabilizer, was provided. With regard to the limitations described, it is concluded that design features of the different stabilizers affect the extent to which a stabilizer interferes with the usual ankle joint kinematics. Future refinements in design must consider the potential for the stabilizer to interfere with the desired range of motion during dynamic activities such as landing. In this way, the design of the "ideal brace" as proposed by Garrick and Requa (6) will be closer to being realized, and protection from inversion ankle sprains will be provided without compromising the performance of the lower extremity when landing.

The authors gratefully acknowledge support from the National Science Foundation Instrumentation and Laboratory Improvement Program (DUE-935 1860); the Illinois Association for Health, Physical Education, Recreation, and Dance Jump Rope for Heart program; and the Illinois State University research grant program. Stabilizers used in the study were contributed by the manufacturers, and use of a particular model of stabilizer in the study does not constitute endorsement by the authors.

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