The Effect of Ankle Bracing on Kinematics in Simulated Sprain and Drop Landings

A Double-Blind, Placebo-Controlled Study

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Background: The efficacy of external ankle braces to protect against sudden inversion sprain has yet to be determined while taking into account the possible placebo effect of brace application.

Purpose: To assess the protective effect of an external ankle brace on ankle kinematics during simulated inversion sprain and single-legged drop landings among individuals with a history of unilateral lateral ankle sprain.

Hypothesis: The primary hypothesis was that active and placebo external braces would reduce inversion angle during simulated inversion sprain.

Study Design: Controlled laboratory study.

Methods: Sixteen participants with ankle instability and previous sprain performed single-legged drop landings and sudden inversion tilt perturbations. Kinematics of the affected limb were assessed in 3 conditions (active bracing, passive placebo bracing, and unbraced) across 2 measurement days. Participators and investigators were blinded to the brace type tested. The effect of bracing on kinematics was assessed with repeated measures analysis of variance with statistical parametric mapping, with post hoc tests performed for significant interactions.

Results: Only active bracing reduced inversion angles during a sudden ankle inversion when compared with the unbraced condition. This reduction was apparent between 65 and 140 milliseconds after the initial fall. No significant differences in inversion angle were found between the passive placebo brace and unbraced conditions during sudden ankle inversion. Furthermore, no significant differences were found among all tested conditions in the sagittal plane kinematics at the knee and ankle.

Conclusion: During an inversion sprain, only the actively protecting ankle brace limited inversion angles among participants. These results do not indicate a placebo effect of external bracing for patients with ankle instability and a history of unilateral ankle sprain. Furthermore, sagittal plane knee kinematics appear to remain unaffected by bracing during single-legged landing, owing to the limited effects of bracing on sagittal ankle kinematics. These results highlight the role of brace design on biomechanical function during sports-related and injury-prone movements.

Clinical Relevance: Athletes prone to reinjury after lateral ankle sprain may benefit from brace designs that allow for full sagittal range of motion but restrict only frontal plane motion.

Keywords: kinematics; ankle brace; ankle inversion; lateral ankle sprain

During participation in sports, the ankle is the most frequently injured joint in the body.[16,31] Eighty-five percent of these injuries are sprains, which are often inversion sprains of the lateral ligaments.[26] Although incidence is high, lateral ankle sprain (LAS) is typically seen in the clinic as being relatively benign,[3] which may contribute to lasting complications,[3] such as chronic ankle instability, higher mechanical laxity,[9] and higher reinjury risk.[28] As a result, there is persistent disability in the ankle after LAS[27] regardless of initial treatment,[23] and external supports have been employed to resist further inversion injury in this population.

Ideally, a prophylactic ankle support would reduce either the maximal angle or the angular velocity of a sudden ankle inversion to minimize the chance of injury.

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Bracing and taping are often interchangeably used in practice; however, external bracing was shown to offer a slower inversion velocity when directly compared with taping.[21] Another added benefit of bracing is the relative ease of use, as ankle taping takes comparatively more time and is more user dependent for correct application. The mechanical support offered by bracing suggests that it may be more effective in preventing reinjury in the frontal plane.

An optimal external ankle support should allow unrestricted sagittal plane movement. Current designs aim to address this with various semirigid or hinged variants. Given that these injuries commonly occur during sports while an athlete is landing from a height, single-legged drop landing tests offer an ideal model for assessing ankle function within an ankle brace. However, most brace designs continuously limit frontal and sagittal plane mobility during noninjury movements, such as running,[38] which may lead to diminished athletic performance. An ideal brace would selectively restrict inversion at higher velocities only when the existing mechanical structures are unable to support the ankle.

An inherent limitation in the assessment of an external ankle brace is the confounding effect of cognitive bias, where it remains unclear if the outcomes were affected by the device or by the user's expectation.[5] The inclusion of a placebo within a blinded study is warranted to investigate the effects of an external support[5]; yet to date, few studies assessing ankle bracing have incorporated this into their study design.[‡] In a recent blinded study, Sawkins and colleagues[35] found no differences among real taping, placebo taping, and no taping during hopping and a star excursion test, suggesting that for these tasks, the combination of patient confidence and taping is important for injury prevention but that the placebo effect for taping remains unclear. To date, no study investigating external ankle supports has considered the placebo effect on investigators and users in their assessments.

The purpose of the present study was to assess the protective effect of an active external ankle brace that selectively restricts inversion velocity during possible reinjury, taking into account the possible placebo effect of brace application. To investigate this, a repeated measures, double-blind, placebo-controlled study was conducted within a cohort of patients with previous unilateral LAS. We hypothesized that active and placebo external braces would both be capable of reducing angles during a sudden inversion when compared with no bracing. A further aim of this study was to determine if an external ankle brace affects sagittal plane kinematics during single-limb drop landings among patients with a history of unilateral LAS.

METHODS

Participants

The present study was a part of a larger experimental protocol that aimed to assess the effect of external ankle bracing on movement, which also included gait analysis and balance assessment. The experimental protocol completed by the participants comprised an ankle inversion test, walking, jogging, a unilateral balance test, and single-legged landing. However, the present study included only the kinematic and kinetic data obtained during the inversion test and the single-legged landing.

Sixteen participants with a history of unilateral LAS were recruited for this study (7 female and 9 male; mean ± SD age, 30.9 ± 4.7 years; body mass, 73.4 ± 11.9 kg; body height, 176.4 ± 9.5 cm). Participants had self-reported unilateral ankle instability and "giving way," a history of initial acute LAS that was at least 1 year prior, and regular participation in sports for a minimum of 3 hours per week. Exclusion criteria included a history of other lower extremity injuries or surgery, injury within the past 4 weeks, vestibular or balance disorders, foot deformities, generalized hypermobility, or any further condition that could affect test performance. Foot and Ankle Outcome Scores[34] were assessed before measurement. All protocols were developed with reference to the Declaration of Helsinki. The local ethics committee (EA1/335/16) approved the study, and all patients gave their informed consent before participation.

Study Design and Protocol

All participants were required to attend 2 measurement sessions in a motion capture laboratory setting within 1 week. At each measurement, participants were tested under 2 shod conditions: first, a baseline condition without an orthotic brace, followed by an intervention condition with an orthotic brace. The functional test protocol was identical for both conditions and completed in the same order, with single-legged drop landings first, followed by inversion plate tests (Appendix Figure 1, available in the online version of this article). Participants wore the same athletic shoes at both sessions. Data collection was limited to the LAS-affected limb for all tests.

The braces used for this investigation (Betterguards GmbH) (Figure 1) were manufactured to be identical, save for an exchangeable module that would resist frontal plane motion at high inversion velocity (hereafter, an "active" brace) or passively allow frontal plane motion at all velocities ("passive" brace). The active module contained an unpowered energy-absorbing system with a dilatant fluid to reduce inversion angles, whereas the passive brace had no such module and had an identical, flexible elastic band. The module is placed laterally within the brace and is connected to the customized insole with a band. The connection between the brace and the insole is placed in a way that the module is pulled when the foot is inverted. The brace was put on the patient's affected foot by external investigators for proper fit. Since the brace required a physical connection to an insole within the athletic shoe, identical insoles were placed in both shoes for both conditions (with and without brace) to exclude the influence of the insole on test results.

Two external investigators were unblinded and randomized the brace intervention so that the active brace was worn during one session and the passive brace during

‡References 2, 8, 10, 19, 20, 22, 24, 30, 36, 39.

Figure 1. Depiction of the external ankle brace used for testing (left), with the exchangeable module indicated by the dashed line, which is visible only upon lifting the cushioning pads (right). The brace was designed to ensure that participants and investigators were blinded to the module used (active or passive).

the other. The participants and the primary investigators were both blinded to which orthotic was being tested at each session. Furthermore, both blinded groups (participants and investigators) were not allowed to apply or touch the orthotic during and after measurement sessions. All participants performed a standardized warm-up protocol that included walking and jogging for a minimum of 15 minutes.

Single-Legged Drop Landing

For each condition, participants performed a set of 3 single-legged drop landings from a 0.2 m–high platform, similar to the task described by Gardner and colleagues.[19] While balancing near the edge of the platform standing only on the tested leg, participants were asked to lean forward and land on the same leg on a forceplate (sampling frequency, 1000 Hz; AMTI). Drop landings were included for analysis if participants were able to stand with an outstretched knee after maximal flexion. Before the first data collection, all participants were given oral instructions, a demonstration of the task, and at least 1 practice test for familiarization and to ensure proper performance.

Three-dimensional kinematic data of the lower extremities were gathered with a set of 67 reflective markers placed on the limb and shoes, tracked by an infrared motion capture system operating at 200 Hz (10 MX-S cameras; VICON). Markers were placed as recommended by Kratzenstein and colleagues,[25] and functional movements, including a star-arc motion[6] and flexion-extension of the knee, were used to identify the hip joint center[13] and tibiofemoral axes of rotation,[14] respectively. The optimal common shape technique[40] was employed to minimize soft tissue artifact. Markers were placed at bony landmarks palpated on the pelvis, tibia, ankle, and foot with double-sided adhesive tape. Bony landmarks included the anterior and posterior superior iliac spine, greater trochanter, tibial tuberosity,

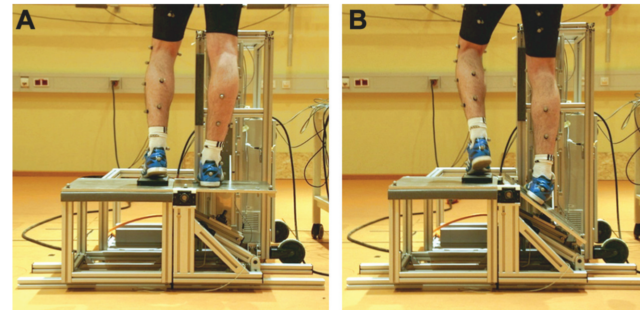

Figure 2. (A) Initial and (B) end positions of the single-legged inversion tilt as performed on the custom-built tilting platform.

fibular head, first and fifth metatarsals, and the medial and lateral aspects of the following: knee epicondyles, ankle malloli, and calcaneus. Given its design, the brace did not obstruct the malleoli, so the bony aspects were directly marked for assessment. Further markers were symmetrically attached to the thigh, shank, and foot. Sagittal knee angles were calculated with the OSSCA projection,[40] and ankle angles were calculated with ISB standards[42] from the time of initial ground contact to 250 milliseconds afterward.

Single-Legged Inversion Tilt

Following the single-legged drop landing test, a series of tests were performed whereby an unexpected unilateral foot inversion was induced on a custom-built tilting platform (Figure 2) controlled by an external motor (Servomotor EMMS-AS-140-L-HS-RSB; Festo AG & Co KG) with a maximal inversion angle of 30° (Figure 2). A set of 10 randomized trials were performed on the tested leg, with 5 trials at 400 deg/s and 5 trials at 150 deg/s, simulating a "fast" and "physiological" inversion movement, respectively, above and below a previously suggested threshold of 300 deg/s.[7]

All patients were asked to adopt a particular stance (Figure 2A), with the knee on the testing leg outstretched and with the contralateral foot on a small forceplate (sampling frequency, 100 Hz; FP4, Biometrics Ltd), which was built onto the nontilting portion of the platform. Patients placed 80% of their bodyweight onto the tilting platform. An investigator with real-time monitoring of the forceplate values guided patients to 20% bodyweight on the contralateral limb. Once this measurement was steady, the platform was triggered to fall by an external control (Figure 2B) (Festo Configuration Tool, v 1.2.3.6; Festo AG & Co KG).

Kinematic data of the tested leg were gathered with the same camera system, with an increased sampling frequency of 400 Hz. Within this measurement, only the inversion angle of the ipsilateral limb was calculated for each trial. The inversion angle was cropped to a predetermined time of 200 milliseconds starting from the initial movement of the dropping platform. The vertical displacement of a reflective marker placed at the far edge of the inversion platform was used to identify the initial movement.

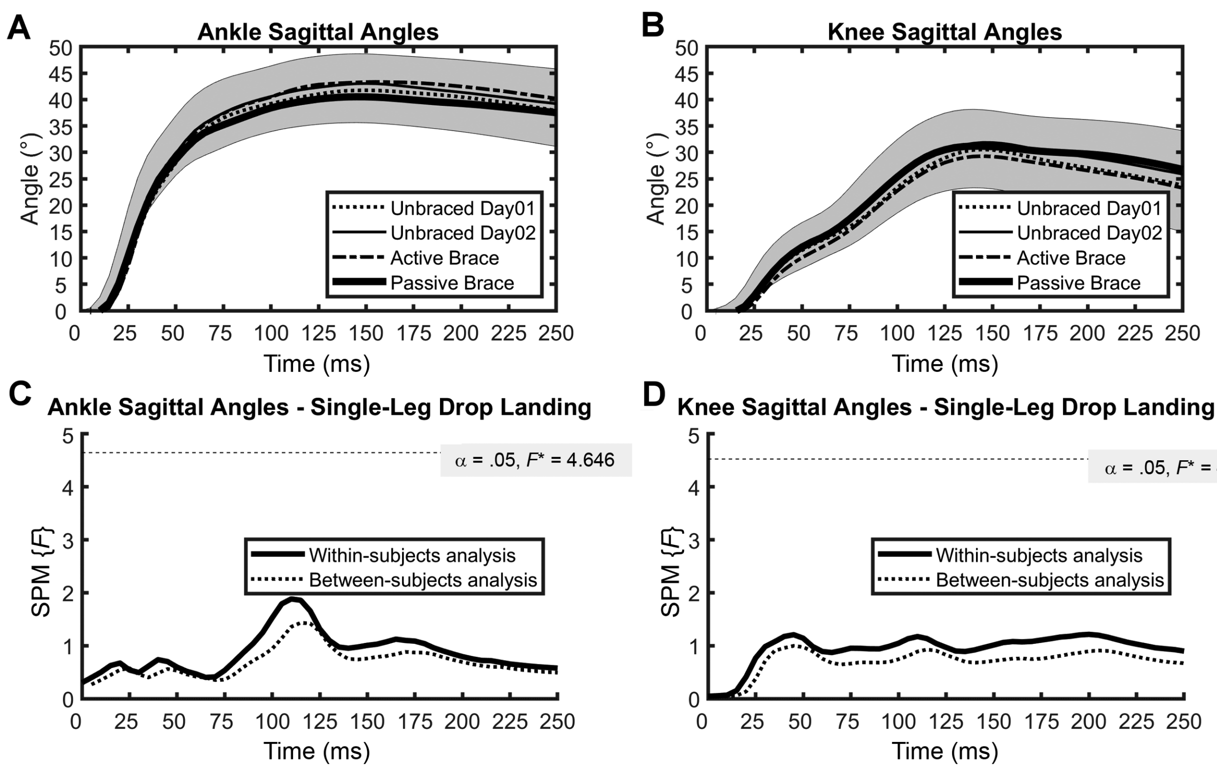

Figure 3. Mean curves (top row) and SPM results (bottom row) for the repeated measures analyses of variance comparing (A) ankle and (B) knee sagittal angles during the single-legged drop landing across all conditions. The significant threshold for SPM was not exceeded for (C) the ankle, SPM{*F*} = 4.646 (thin dotted line), nor for (D) the knee, SPM{*F*} = 4.524, for within- and between-subjects analyses. Pooled SD of the group means is indicated by the gray clouds in panels A and B for each time point. SPM, statistical parametric mapping.

Statistical Analysis

To investigate the effect of the brace on (1) the ankle and knee sagittal angles during the single-legged drop landing and (2) the ankle frontal angles during the single-legged inversion tilt, statistical parametric mapping (SPM) for a 1-way repeated measures analysis of variance (ANOVA) design was applied to the 2 joints in both planes, with the brace as the independent variable.[18] SPM offers a statistical analysis where the entire time series is considered and time regions of significant effect of the independent variable can be identified.[18] Thus, when SPM is applied to a time-normalized period, significant group or brace-related effects can be identified within the time domain. Briefly, each mean joint angle trajectory from the patients during each trial was regarded as a single vector field, $\mathbf{r}(q) = \{rx(q)\ ry(q)\}$, where q represents time and F statistics were computed for separately at each time point q. The analytical description of Gaussian field behavior by random field theory was used to calculate the critical threshold F^* that identically smooth Gaussian fields would reach in only 5% of identical repeated experiments. F trajectories exceeding F^* would indicate a significant effect of the independent variable.[1] In case of an overall significant effect, post hoc paired SPM t tests were applied to compare the joint angles among the different braces. Details of the SPM analysis are reported elsewhere.[18,32] All SPM analyses were implemented in the MATLAB environment with open-source spm1d code (v M.0.4.5).

RESULTS

Foot and Ankle Outcome Scores

Self-reported scores indicated that previous unilateral LAS most affected the quality of life (subscore, 71.5 ± 20.3 out of maximal 100). The cohort also exhibited a number of negative symptoms (78.3 ± 17) and some minor effects on sports participation (87.5 ± 13.4). There were limited reports of ankle pain (90.5 ± 10.4), and activities of daily living appeared to be least affected (97.5 ± 3).

Single-Legged Drop Landing

Sagittal plane angles of the ankle and knee for all conditions are presented in Figure 3A and B, respectively. A repeated measures ANOVA yielded no significant differences throughout the initial landing phase, with all SPM{F} values remaining below the critical significance thresholds for the ankle and knee (Figure 3, C and D).

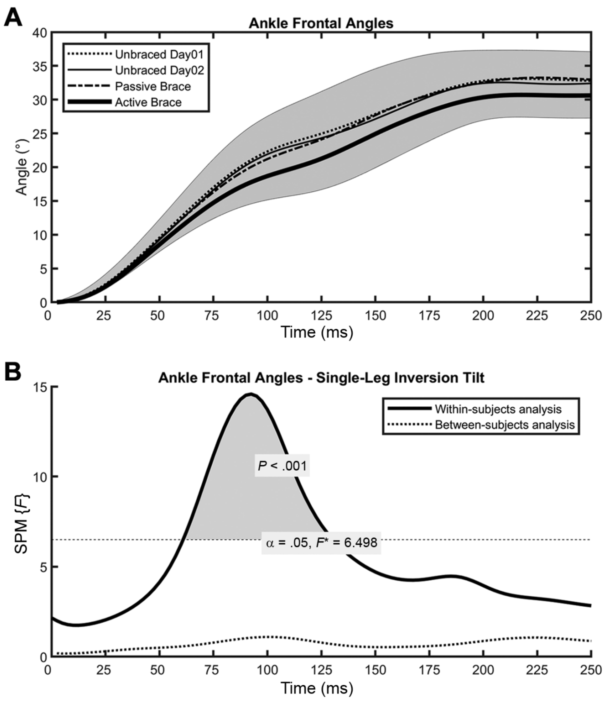

Figure 4. Mean (A) curves and (B) SPM results from the analysis of variance comparing inversion angles across all conditions for the sudden inversion plate tilt. The significant threshold, indicated by the dotted line at SPM{F} = 6.498, was exceeded for within-subjects analysis between 60 and 125 milliseconds after the initial fall (shaded gray area). Pooled SD of the group means is indicated by the gray cloud in panel A for each time point. SPM, statistical parametric mapping.

Single-Legged Inversion Tilt

A repeated measures ANOVA of the ankle inversion angle comparing all conditions for the fast tilt speed of 400 deg/s indicated a significant effect between 60 and 125 milliseconds after initial drop (Figure 4). No differences were found across all conditions in tests that were performed at the slow drop speed of 150 deg/s.

Comparison of the active brace and the unbraced condition (Figure 5A) yielded a significant effect (P < .001) between 65 and 140 milliseconds after the initial drop (Figure 5D), indicating lower angles on the ankle equipped with the active brace. At 180 to 200 milliseconds after the initial drop, another significant effect (P = .013) indicated a similar result. Comparison of the passive brace and the unbraced condition did not yield any differences during the entire drop time (Figure 5, B and E). The post hoc t test found no interday differences between the unbraced measurements (Figure 5, C and F).

DISCUSSION

This study assessed the effect of a selectively restrictive ankle brace on sagittal kinematics during simulated sprain and drop landings among patients with a history of unilateral ankle sprain, while accounting for a possible placebo effect. Our first hypothesis was partially supported, as the active external brace was able to reduce angles during a sudden inversion, but the placebo brace did not exhibit any differences when compared with an unbraced condition. Furthermore, we did not find any differences in the knee and ankle sagittal angles across all conditions during drop landings. These results indicate that for the design tested, the brace effectively protects the ankle from inversion while allowing unrestricted sagittal movements of the ankle and knee, and these effects are not due to the mere act of placing an external device on the ankle.

First, participants with a history of LAS were able to reduce inversion angles during a simulated inversion sprain when wearing an actively protecting brace, in comparison with both the unbraced and placebo brace conditions. These results are in agreement with similar experimental setups that found reduced angles among healthy participants with semirigid,[8,39] hinged,[2] and lace-up[8] supports as compared with unbraced conditions. The resultant reduction of maximal inversion angle by 5° is comparable with previous reports from Tang et al,[39] who found 3° reduction when comparing the Aircast brace and unbraced barefoot conditions in a similar inversion tilt test. These collective results are lower than the higher reductions found by Alfuth et al[2] and Cordova et al,[8] who found roughly 17° and 16.4° in different brace settings, respectively. These differences may be due to various brace designs, such as semirigid versus rigid. Furthermore, all of these previous reports were performed with healthy participants and not participants with previous LAS injury. Given the brace's minimal design, direct access to both malleoli was available for marker placement, ensuring that kinematics of the ankle were measured and not those of the brace itself, as previously reported.[39] Previous tests either did not specifically control for weightbearing on the tested leg or assumed that weight distribution was even between legs.[2,8] Since we ensured that participants always placed 80% of their body weight on the tested limb, we could ensure that the inversion tilt was performed similarly across patients and measurement days. By controlling these parameters, in addition to the motor-controlled velocity of the inversion plate and the potential effect of a placebo, we can be confident in the kinematic results presented here.

Second, participants with a history of LAS showed no particular differences in knee and ankle sagittal angles during a single-legged drop landing among all tested conditions, which implies that freedom of movement in the sagittal plane is unaffected by this brace design. Gardner et al[19] found that a more restrictive brace reduced the eccentric energy absorbed at the ankle but not in braces that allow sagittal plane movement. Yet Cordova et al[10] found that closed basket weave taping and semirigid bracing led to lower knee and ankle mobility during single-legged landing. These collective results indicate the importance of brace design on landing lower extremity kinematics and that device-dependent sagittal plane restriction at the ankle may negatively affect the knee.[29] Within the investigated cohort, self-reported Foot and Ankle Outcome Scores indicate that

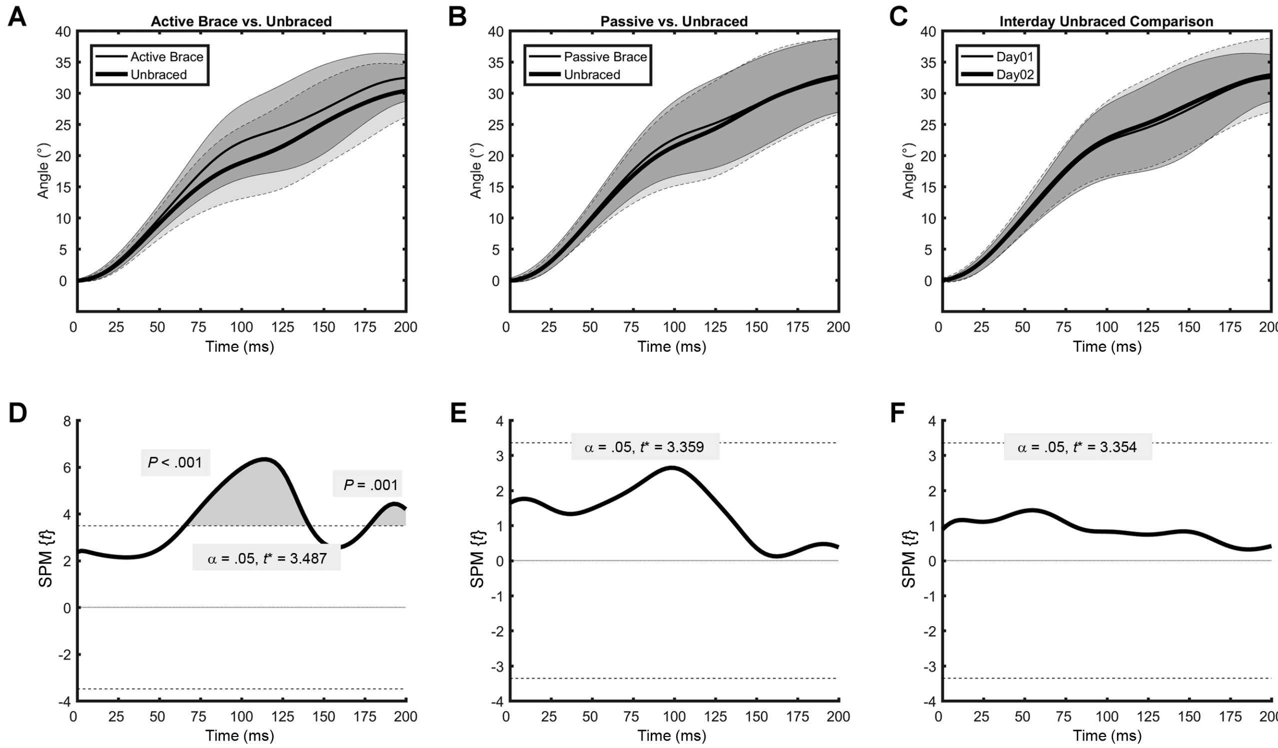

Figure 5. Mean ankle inversion angles during the single-legged inversion tilt test (top row; clouds indicate SD) and corresponding SPM *t*-test analyses (bottom row). (A, D) Inversion angles of the active brace appeared lower than the unbraced condition, and an SPM *t* test indicates that the significance threshold (dotted line), SPM{*F*} = 3.487, was exceeded between 65 and 140 milliseconds and between 180 and 200 milliseconds after initial fall (shaded gray area). (B, E) Passive brace and unbraced inversion angles did not exceed the significant threshold (dotted line), SPM{*F*} = 3.359. (C, F) Similarly, interday comparison of the mean unbraced conditions did not yield significant differences, SPM{*F*} = 3.342. SPM, statistical parametric mapping.

the previous unilateral LAS injury did not greatly hinder participation in sports, which excludes the possibility that patients were unable to perform the drop jump properly. The data presented here imply that when ankle sagittal mobility is unrestricted by a brace, knee sagittal plane mobility remains unchanged from an unbraced condition.

These results have important implications for athletes with previous unilateral LAS who wish to continue participation in high-impact sports. Video analyses of acute sprains during elite matches indicate that volleyball[37] and tennis players[15] sustain ankle sprain upon landing with sudden ankle inversion and internal rotation[15] and with the absence of plantarflexion.[37] Reinjury and recurrent ankle sprain occur at a rate as high as 60% in sporting populations,[4] and external ankle bracing was found to be more effective than tape to prevent reinjury.[41] Previous work indicated that patients with functional ankle instability demonstrate a slower dorsiflexion rate as compared with healthy controls during an unbraced drop jump landing task at 90 to 200 milliseconds after initial contact.[11] This further emphasizes the importance of freedom of sagittal movement among LAS patients, as bracing may reduce maximal dorsiflexion during landing and lead to higher ground-reaction forces and compensatory knee movement.[29] If the mechanism of reinjury is similar to that of a first-time LAS, the necessity of an adequate support that allows both freedom of sagittal movement and frontal plane protection would best protect against further injury.

The present study was limited to assessing the joint kinematics during the 2 tasks and did not account for the activity of muscle surrounding the ankle and knee joint. Therefore, it cannot be excluded that wearing a brace (passive or active) altered the muscle activity of more than one muscle. It was suggested that patients with chronic ankle instability alter ankle motor control owing to impaired sensory feedback from the ligaments spanning the ankle,[17,33] and it could be speculated that wearing a brace or using ankle taping could provide compensatory sensory feedback from movement-induced stimulation of receptors in the skin. Thus, future studies should elucidate the potential altered activity of muscles spanning the knee and ankle during various tasks when an ankle brace is worn.

Another limitation of the present study was that although all participants had a history of unilateral LAS, the time from the first acute LAS event varied. All participants, however, reported recurrent episodes of instability and "giving way" since the initial event on the same side. Furthermore, at 30 years, the mean age of our patient group was slightly higher than that of participants in previous works,[12,19] which may affect interpretation and direct comparison of these results. However, to ensure homogeneity within the investigated cohort, we ensured that all participants were free of any other injury, did not sustain recent injury, and continued to participate in athletic activities regularly.

In conclusion, this study investigated the protective effect of an external ankle brace while accounting for a possible placebo effect of brace application. The results indicate that during a sudden inversion movement, there is no placebo effect for patients with previous LAS and that only an actively protecting brace protects from reinjury. These results further suggest that a brace design that restricts motion in only the frontal plane and not in the sagittal plane of the ankle may be ideal for use in high-impact sports, particularly for landing on a single leg. Furthermore, these results indicate that sagittal knee and ankle kinematics remain unaffected when an ankle support is worn that allows sagittal plane mobility.

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