*Journal of Athletic Training* 2015;50(9):893–904
doi: 10.4085/1062-6050-50.7.07

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# Dynamic Postural-Stability Deficits After Cryotherapy to the Ankle Joint

**Karl Fullam, BSc*†; Brian Caulfield, PhD*†‡; Garrett F. Coughlan, PhD, PT§; Mark McGroarty, BSc*; Eamonn Delahunt, PhD*†**

*School of Public Health, Physiotherapy & Population Science; †Institute for Sport & Health; ‡Insight Centre for Data Analytics, University College Dublin, Ireland; §Irish Rugby Football Union, Dublin, Ireland

***Context:*** Decreased postural stability is a primary risk factor for lower limb musculoskeletal injuries. During athletic competitions, cryotherapy may be applied during short breaks in play or during half-time; however, its effects on postural stability remain unclear.

***Objective:*** To investigate the acute effects of a 15-minute ankle-joint cryotherapy application on dynamic postural stability.

***Design:*** Controlled laboratory study.

***Setting:*** University biomechanics laboratory.

***Patients or Other Participants:*** A total of 29 elite-level collegiate male field-sport athletes (age = 20.8 ± 1.12 years, height = 1.80 ± 0.06 m, mass = 81.89 ± 8.59 kg) participated.

***Intervention(s):*** Participants were tested on the anterior (ANT), posterolateral (PL), and posteromedial (PM) reach directions of the Star Excursion Balance Test before and after a 15-minute ankle-joint cryotherapy application.

***Main Outcome Measure(s):*** Normalized reach distances; sagittal-plane kinematics of the hip, knee, and ankle joints; and associated mean velocity of the center-of-pressure path during performance of the ANT, PL, and PM reach directions of the Star Excursion Balance Test.

***Results:*** We observed a decrease in reach-distance scores for the ANT, PL, and PM reach directions from precryotherapy to postcryotherapy ($P < .05$). No differences were observed in hip-, knee-, or ankle-joint sagittal-plane kinematics ($P > .05$). We noted a decrease in mean velocity of the center-of-pressure path from precryotherapy to postcryotherapy ($P < .05$) in all reach directions.

***Conclusions:*** Dynamic postural stability was adversely affected immediately after cryotherapy to the ankle joint.

***Key Words:*** postural balance, lower limb, kinetics

**Key Points**

- A 15-minute cryotherapy application to the ankle joint decreased cutaneous temperature recorded over the anterior talofibular ligament and deltoid ligament.
- Reach distances in the anterior, posterolateral, and posteromedial directions of the Star Excursion Balance Test and center-of-pressure mean velocity decreased after cryotherapy.
- A 15-minute cryotherapy application negatively influenced dynamic postural-stability performance.
- Elite-level field-based athletes should undergo a rewarming period before returning to participation after cryotherapy to the ankle joint to ensure they are not predisposed to injury due to decreased dynamic postural stability.

Cryotherapy is a treatment modality that clinicians commonly use to promote quicker recovery from soft tissue injury in athletes to expedite return to participation. It has been described as the application of cold therapy to living tissues that results in a lower tissue temperature[1,2] and often is used as an immediate treatment method to relieve the acute pain of soft tissue injuries.[1]

The proposed physiologic benefits of cryotherapy for injury have been widely reported. Cryotherapy facilitates edema reduction, produces analgesia,[2,3–6] reduces muscle temperature,[7] and reduces injury-induced inflammation.[8,9] If an athlete incurs a mild sprain or contusion to the ankle joint in a game, the accepted practice during a break in participation (eg, during a half-time period) is to apply cryotherapy to the affected area.

In contrast to the aforementioned positive physiologic effects, Bleakley et al[10] reported in a recent literature review that cryotherapy application negatively affected at least 1 of the following outcomes: vertical-jump height, sprint time, or agility performance. These tasks are integral components of field-based sports, and any decrement in performance could predispose individuals to injury during participation. Pritchard and Saliba[11] suggested that athletic performance may be adversely affected when athletes return to participation immediately after cryotherapy. Furthermore, Costello and Donnelly[12] reported that cryotherapy negatively affects knee-joint positional sense. Uchio et al[13] observed that a 15-minute cryotherapy application increased knee-joint stiffness and decreased knee-joint position sense acuity. Stal et al[14] reported that ankle-joint sensorimotor control as quantified by static postural stability was negatively affected by a 20-minute cooling procedure known as *hypothermic anesthesia*, which is similar to a cryotherapy application.

*Postural stability* refers to the ability to control the center of mass in relation to the base of support to prevent falls[15] and is considered a fundamental component required for performing movement skills.[16] *Dynamic postural stability* can be defined and measured as an assessment of an individual's ability to maintain balance while transitioning from a dynamic to a static state.[17] It is an essential part of an athlete's physical attributes, especially for field sports, given their dynamic nature.[18] Both static and dynamic postural stability result from the complex coordination of central processing from visual, vestibular, and somatosensory pathways, as well as the resultant efferent response.[19]

Static-standing balance ability decreases after cryotherapy application. Cross et al[20] reported that after cryotherapy to the lower extremity, study participants had difficulty maintaining their balance on the treated extremity. More recently, Kernozek et al[21] reported a deficit in mediolateral (ML) ground reaction force variability on the test leg immediately after a 20-minute cryotherapy application to the ankle joint, with a mean difference of 0.48 N relative to precryotherapy measures ($P < .001$; d = 1.20). At the 10-minute and 20-minute measurements postcryotherapy, participants continued to exhibit deficits in static-standing balance. However, traditional laboratory measures of postural stability, including static single-legged stance on instrumented force plates, may not be sensitive enough to detect postural-stability deficits associated with lower limb injury.[22] Furthermore, Hrysomallis et al[23] indicated that postural-stability performance in static positions cannot be extrapolated to dynamic postural-stability performance, concluding that it is not advisable to infer the latter based on the former. Douglas et al[24] reaffirmed this conclusion, postulating that measures of dynamic standing balance may better represent the demands of the lower extremity during functional tasks and, therefore, may be a more appropriate assessment than static standing balance. In addition, Hrysomallis[25] showed that Australian Rules football players with an increased ML center-of-pressure (COP) excursion incurred at least twice as many ankle-ligament injuries as players with average or good postural stability. Kernozek et al[21] and Douglas et al[24] observed that cryotherapy debilitated dynamic postural stability, potentially increasing the risk of lower limb injury.

Considering the potential shortcomings of static postural-stability testing, our contention was that further investigations of the effects of cryotherapy application to the ankle joint on dynamic postural-stability performance are warranted. One potential method to investigate the influence of ankle-joint cryotherapy application on dynamic postural-stability performance is to use the Star Excursion Balance Test (SEBT) as a primary assessment, supplemented by lower limb sagittal-plane motion analysis and force-plate–derived kinetic assessment. Therefore, the purpose of our study was to evaluate the acute influence of a 15-minute cryotherapy application to the ankle joint on dynamic postural stability as quantified by performance on selected reach directions of the SEBT, associated lower limb sagittal-plane kinematic profiles, and kinetic measures of postural stability. We hypothesized that a 15-minute cryotherapy application to the ankle joint would result in decreased reach distances on the selected directions of the SEBT and altered sagittal-plane ankle-joint kinematics and kinetic measures of postural stability.

## METHODS

### Participants

Twenty-nine elite-level collegiate male field-sport athletes (age = 20.80 ± 1.12 years, height = 1.80 ± 0.06 m, mass = 81.89 ± 8.59 kg, body mass index = 25.33 ± 2.2 kg/m$^2$) were recruited from the university population and volunteered for the study. Inclusion criteria required recruits to be between 18 and 30 years of age and to currently participate or train regularly with an elite-level collegiate team. All athletes were fully engaged in field sports (eg, rugby union, soccer, hurling, or Gaelic football). Further inclusion criteria required participants to have no history of ankle-joint or lower limb injury in the 3 months before the study, neurologic or balance disorder, or lower limb fracture. All participants provided written informed consent, and the study was approved by the University College Dublin Human Research Ethics Committee.

### Procedures

All testing was undertaken in a university motion-analysis laboratory. Participants attended the laboratory on 1 occasion. Upon arrival for the testing session, they were informed of and familiarized with the testing procedure. All testing was supervised by a chartered physiotherapist (K.F.).

### Star Excursion Balance Test Protocol

Based on previously published research,[26,27] we chose the anterior (ANT), posterolateral (PL), and posteromedial (PM) reach directions of the SEBT. To perform the SEBT, participants initially stood barefoot with their left and right feet on 2 adjacent force plates, similar to previously published methods.[28]

Before each test session, participants were instructed in the correct performance of the test and allowed 4 practice trials in each direction, as advocated by Robinson and Gribble.[16] The nondominant lower extremity was the test leg, as it corresponded with the weight-bearing limb when a participant was kicking a football (ie, the nonpreferential limb was the test leg). Three consecutive trials in each direction were performed at 2 time points: time 1 (precryotherapy) and time 2 (postcryotherapy). The order of performance of each directional component was randomized across participants using a random sequence generator.

Participants initially stood with their big toes positioned at the center of a grid laid on the laboratory floor and extending from the force plate directly under the test leg. Each trial was initiated when the participant transitioned from double-legged to single-legged stance, with the trial ending when he returned to double-legged stance.[29] We used the vertical component of the ground reaction force data to determine the onset and termination of each trial as previously described.[28] A 1.5-m measuring tape in each reach direction allowed us to easily quantify reach-distance scores. We read reach distances from the center of the grid to the point of maximum reach, which was observed visually and noted by 1 of the investigators (K.F.). The same investigator was responsible for precryotherapy and postcryotherapy measurements. Reach distances were divided by limb length, as measured from the anterior-superior iliac spine to the ipsilateral medial malleolus, and multiplied by 100 to calculate a dependent variable that represented reach distance as a percentage of limb length.[30]

During the formal testing procedure, a reach trial was deemed invalid if participants removed their hands from their hips, put excessive weight through the reach foot, did not return to the starting position, or did not touch down on

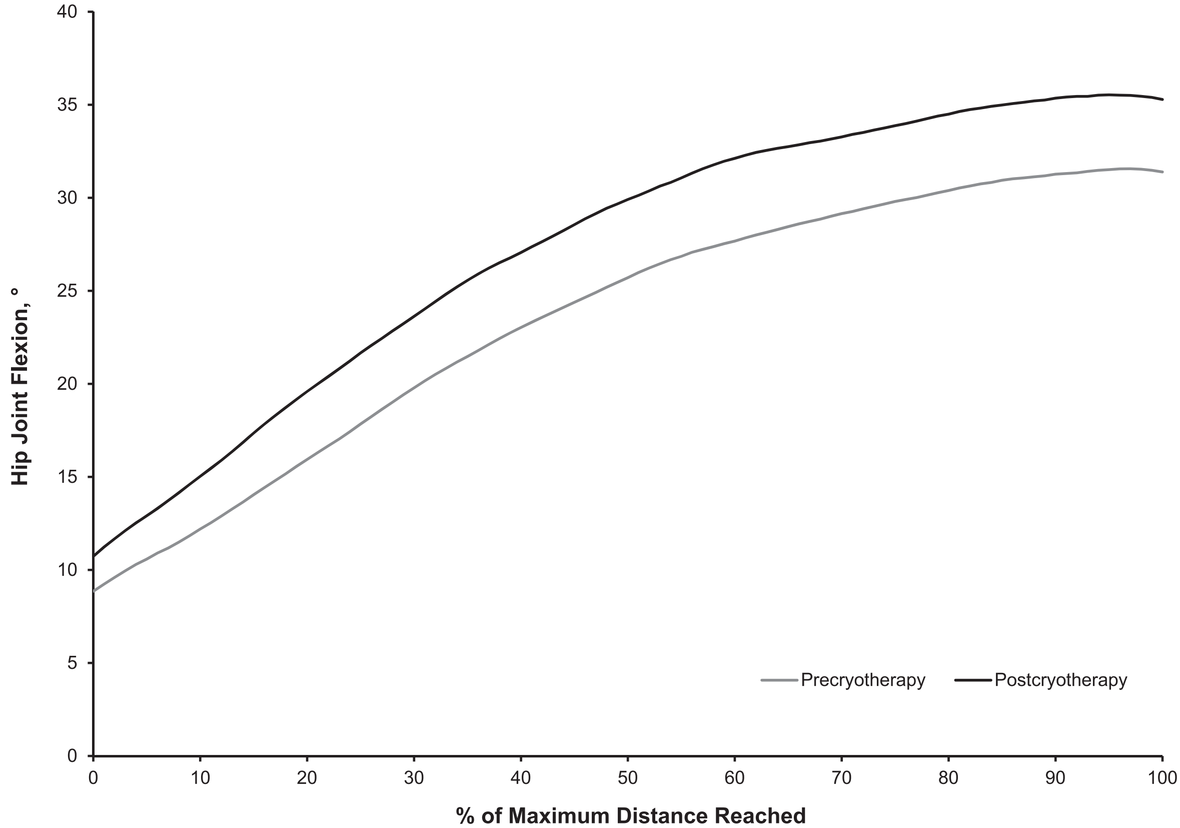


**Figure 1. Hip-joint flexion in the anterior reach direction of the Star Excursion Balance Test. 0 = Start of trial, 100 = point of maximum reach.**

the tape measure. Furthermore, if participants lost their balance or were unable to maintain a unilateral-stance position during trial performance, the trial was deemed unsuccessful. Unsuccessful trials were discarded and additional trials were completed accordingly.

## Kinematic Analysis

Kinematic data acquisition occurred at 200 Hz using 3 Codamotion CX1 units (Charnwood Dynamics Ltd, Leicestershire, UK), which were integrated fully with 2 walkway-embedded force plates (Advanced Medical Technology Inc, Watertown, MA) sampling at 100 Hz.

We marked specific anatomical landmarks on each participant with a skin-marker pencil before recording anthropometric values and attaching the markers and marker wands as outlined in previous research.[31,32] For all participants, the same investigator (K.F.) applied the markers and wands.

Kinematic data were calculated by comparing the angular orientations of the coordinate systems of adjacent limb segments using the angular coupling set Euler angles to represent clinical rotations in 3 dimensions. Marker positions within a Cartesian frame were processed into rotation angles using vector algebra and trigonometry (Codamotion CX1 User Guide). Joint angular displacements were calculated for the hip, knee, and ankle joints in the sagittal plane. We analyzed kinematic data using the Codamotion software with the following axis conventions: x axis = *frontal-plane motion*; y axis = *sagittal-plane motion*; z axis = *transverse-plane motion*. Kinematic data for each SEBT trial were extracted and converted to Excel (version 2010; Microsoft Corporation, Redmond, WA) file format by converting the number of output samples to 100 + 1 in the data-export option of the Codamotion software, which represented the complete SEBT trial as 100%, for averaging and further analysis. We combined the 3 normalized trials for each participant in each reach direction to create an average ensemble curve for each participant, and then we calculated group profiles. This specific analysis technique has been used in our laboratory.[31–36] In this study, we evaluated only the results of hip-, knee-, and ankle-joint sagittal-plane angular displacement, as Robinson and Gribble[16] showed that hip-joint and knee-joint flexion, separately and in combination, accounted for 65% and 95%, respectively, of the variance in SEBT reach distances.

## Kinetic Analysis

Kinetic data were acquired at 100 Hz using the 2 walkway-embedded force plates, which were synchronized with the Codamotion CX1 units. Center of pressure is a bivariate distribution jointly defined by the anteroposterior (AP) and ML coordinates that, in a time series, define the COP path relative to the origin of the force plate.[37]

Hybrid time-domain measures modeled the COP stabilogram with a combination of distance measures. The kinetic dependent variable of interest was the mean velocity (MVELO), which is the average velocity of the COP. The use of MVELO for postural-stability analysis was outlined by Prieto et al.[37] In effect, this normalized the total excursions to the analysis interval. The COP time series

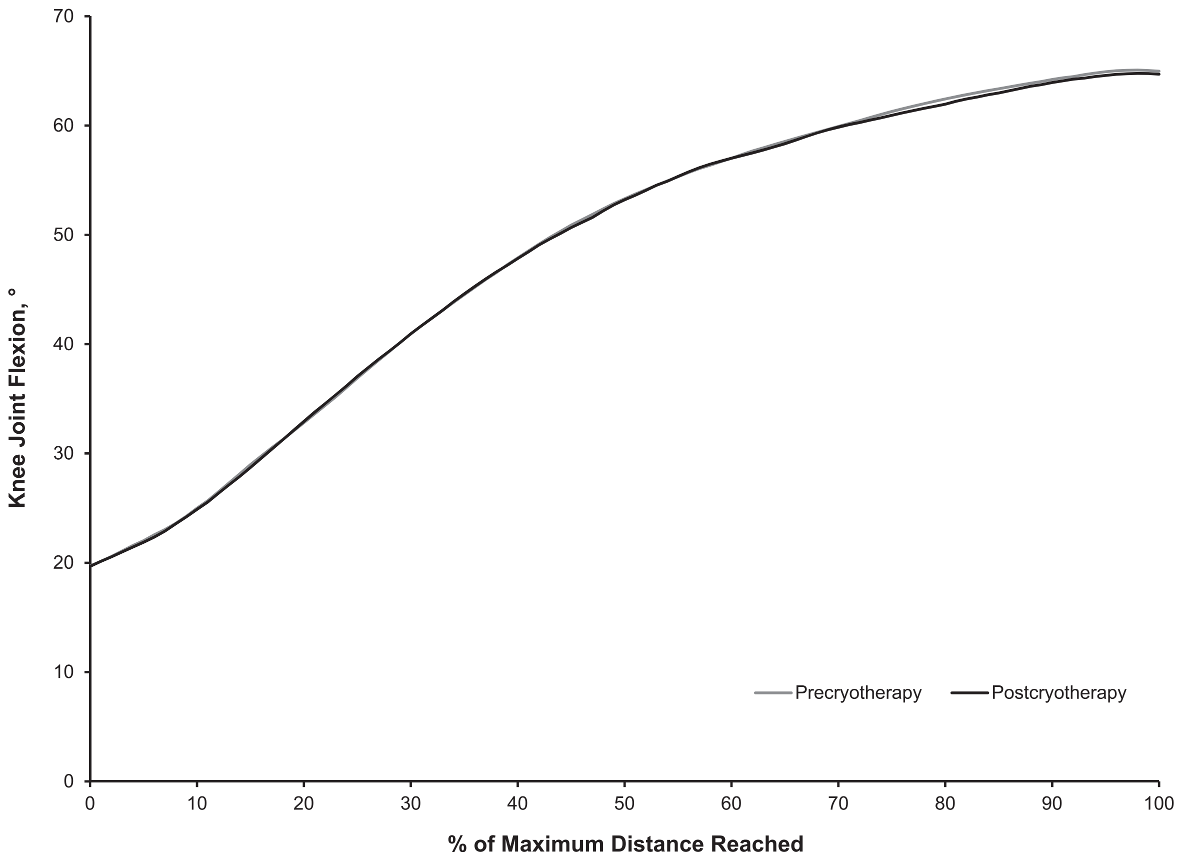


**Figure 2. Knee-joint flexion in the anterior reach direction of the Star Excursion Balance Test. 0 = Start of trial, 100 = point of maximum reach.**

were filtered to the frequency range of interest to minimize the quantization noise that may inadvertently inflate measures such as mean velocity and total excursions:

$$\mathrm{MVELO} = \frac{\mathrm{TOTEX}}{\mathrm{T}},$$

where TOTEX was the total length of the COP path and was approximated by the sum of the distances between consecutive points on the COP path and T was the analysis interval.

## Cryotherapy Protocol

The cooling procedure for the ankle joint was initiated by using an Aircast Cryo/Cuff IC Cooler (DJO Global, Vista, CA). The reservoir of the device was filled with water and crushed ice as directed by the manufacturer. The Aircast Cryo/Cuff IC Cooler was then flushed with ice-cold water. On completion of the initial SEBT, the participant lay supine, and the investigator applied the Aircast Cryo/Cuff IC Cooler and refilled it with ice-cold water. We chose a 15-minute cooling period to simulate the half-time interval of a match seen in most field sports and because it is a common duration used for precooling.[38–41] During the cooling period, the Aircast Cryo/Cuff IC Cooler was recooled every 3 minutes, with the drained water remaining in the ice reservoir for 30 seconds to maintain a stable temperature. After the 15-minute period, the Aircast Cryo/Cuff IC Cooler was removed, and the participant performed the SEBT for the second time.

## Monitoring Skin Temperature

Two iButton (Maxim Integrated, San Jose, CA) devices were placed on the origin of the deltoid ligament and anterior talofibular ligament (ATFL) of the nondominant, standing limb before cryotherapy application to obtain a baseline skin temperature measurement of the ankle joint. The iButton device is a computer chip that is enclosed in a 16-mm-thick stainless steel can that monitors thermal exposure. We used the device to measure the thermal response at the ankle joint from baseline skin temperature precryotherapy (time 1) to postcryotherapy (time 2) and again at the completion of the postcryotherapy SEBT (time 3).

## Statistical Analysis

Separate 1-way repeated-measures analyses of variance were conducted to compare temperature recorded over the deltoid ligament and ATFL at time 1 (precryotherapy), time 2 (postcryotherapy), and time 3 (after completion of the postcryotherapy SEBT protocol). When we observed an effect for time, we conducted a Bonferroni pairwise comparison. The $\alpha$ level was set at .05. All effect-size statistics (partial $\eta^2$) were calculated as outlined by Pallant[42] and interpreted according to the recommendations of Cohen[43] as follows: 0.01 = *small*, 0.06 = *moderate*, 0.14 = *large*. We used paired-samples *t* tests to evaluate the effect of cryotherapy application on participants' reach-distance scores in the ANT, PL, and PM reach directions of

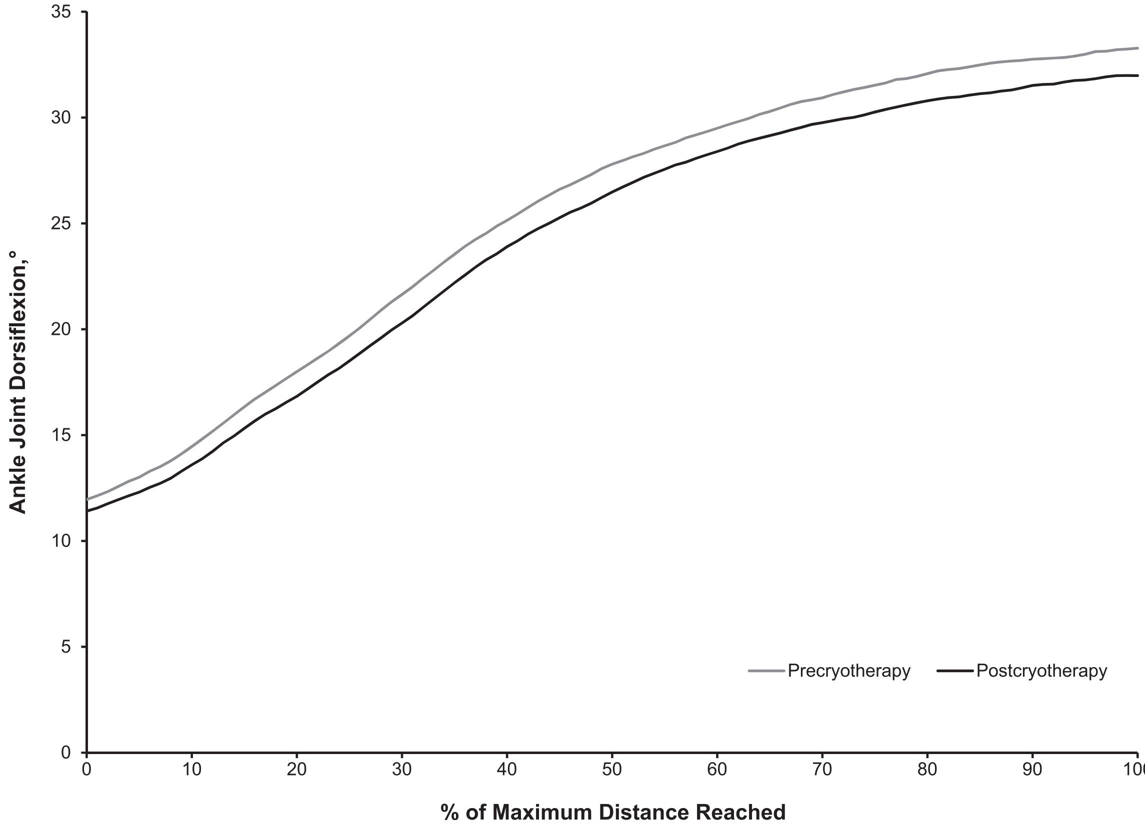


**Figure 3. Ankle-joint dorsiflexion in the anterior reach direction of the Star Excursion Balance Test. 0 = Start of trial, 100 = point of maximum reach.**

the SEBT, as well as the composite (COMP) reach-distance score of the 3 distances. The α level was set at .05.

We calculated time-averaged profiles for hip-, knee-, and ankle-joint sagittal-plane kinematics for each participant in the ANT, PL, and PM reach directions and then group mean profiles (ie, precryotherapy versus postcryotherapy). Differences in precryotherapy and postcryotherapy time-averaged profiles were tested using dependent-samples *t* tests for each data point. This specific analysis technique has been used in our laboratory.[30–34,44,45] Effect sizes were not calculated for this part of the data analysis due to the number of separate comparisons for each kinematic variable. The α level was set at .05.

We used paired-samples *t* tests to evaluate the effect of cryotherapy application on MVELO in the ANT, PL, and PM reach directions of the SEBT. The α level was set at .05. Data were analyzed using SPSS (version 20; IBM Corporation, Chicago, IL).

## RESULTS

### Temperature Recording Over the ATFL and Deltoid Ligament

We observed an effect for time (Wilks $\Lambda = 0.07$, $F_{2,7} = 41.44$, $P < .001$, multivariate partial $\eta^2 = 0.92$). The temperature recorded over the ATFL at time 2 (21.93°C ± 2.21°C) was different from that recorded at time 1 (29.18°C ± 1.18°C) and time 3 (24.13°C ± 2.18°C; $P < .001$). We also noted a difference between the temperatures recorded over the ATFL at time 1 and time 3 ($P < .001$).

For the deltoid ligament, we found an effect for time (Wilks $\Lambda = 0.04$, $F_{2,7} = 73.16$, $P < .001$, multivariate partial $\eta^2 = 0.95$). The temperature recorded over the deltoid ligament at time 2 (22.03°C ± 1.65°C) was different from that recorded at time 1 (28.90°C ± 1.06°C) and time 3 (24.28°C ± 1.74°C; $P < .001$). We also demonstrated a difference between temperatures recorded over the deltoid ligament at times 1 and 3 ($P < .001$).

### Star Excursion Balance Test Reach Distances

We observed a decrease in ANT reach-direction score from precryotherapy (61.78% ± 6.63% of maximum distance reached by the reach foot [% limb length]) to postcryotherapy (59.75% ± 5.74% limb length; $t_{28} = 4.47$, $P < .001$; 2 tailed). The mean difference in ANT reach-direction score was 2.02% limb length (95% confidence interval [CI] = 1.09, 2.95). The $\eta^2$ statistic indicated a large effect size (0.41).

The PM reach-direction score decreased from precryotherapy (113.48% ± 6.35% limb length) to postcryotherapy (108.95% ± 6.44% limb length; $t_{28} = 6.06$, $P < .001$; 2 tailed). The mean difference in PM reach-direction score was 4.52% limb length (95% CI = 2.99, 6.05). The $\eta^2$ statistic indicated a large effect size (0.56).

We found a decrease in PL reach-direction score from precryotherapy (105.07% ± 6.25% limb length) to postcryotherapy (102.24% ± 6.64% limb length; $t_{28} = 4.42$, $P < .001$; 2 tailed). The mean difference in PL reach-direction score was 2.83% limb length (95% CI = 1.52, 4.14). The $\eta^2$ statistic indicated a large effect size (0.41).

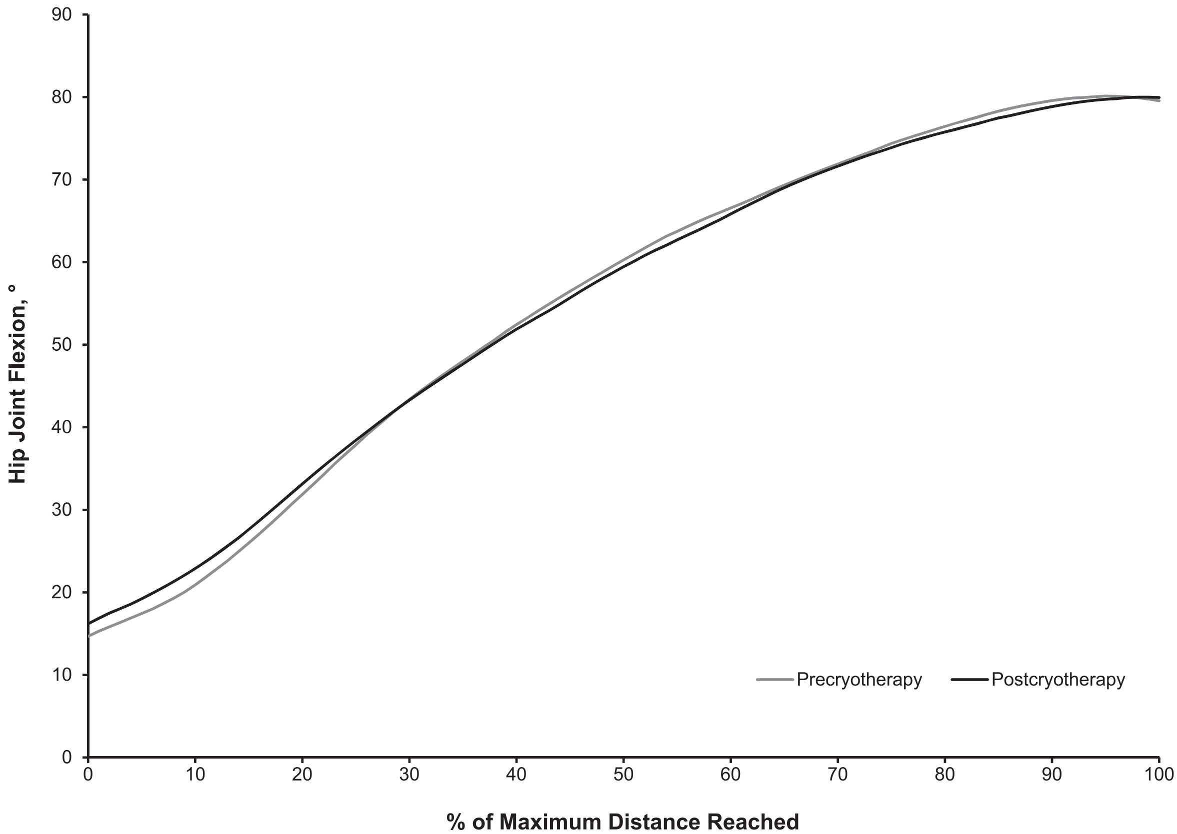


**Figure 4. Hip-joint flexion in the posterolateral reach direction of the Star Excursion Balance Test. 0 = Start of trial, 100 = point of maximum reach.**

The COMP reach-distance score decreased from precryotherapy (98.91% ± 7.44% limb length) to postcryotherapy (95.58% ± 7.07% limb length; $t_{28} = 7.66$, $P < .001$; 2 tailed). The mean difference in COMP reach-distance score was 3.33% limb length (95% CI = 2.44, 4.22). The $\eta^2$ statistic indicated a large effect size (0.67).

## Star Excursion Balance Test Kinematics

We did not observe differences between the precryotherapy and postcryotherapy kinematic profiles during performance of the ANT, PL, or PM reach directions of the SEBT ($P > .05$; Figures 1–9).

## Star Excursion Balance Test Kinetics

The MVELO in the ANT reach direction decreased from precryotherapy (62.96 ± 15.65 mm/s) to postcryotherapy (58.19 ± 13.53 mm/s; $t_{23} = 2.80$, $P = .01$; 2 tailed). The mean difference in MVELO in the ANT reach direction was 4.77 mm/s (95% CI = 1.24, 8.29), and the $\eta^2$ statistic indicated a large effect size (0.26).

The MVELO in the PL reach direction decreased from precryotherapy (75.07 ± 18.54 mm/s) to postcryotherapy (70.49 ± 15.38 mm/s; $t_{23} = 2.18$, $P = .04$; 2-tailed). The mean difference in MVELO in the PL reach direction was 4.58 mm/s (95% CI = 0.24, 8.92). The $\eta^2$ statistic indicated a large effect size (0.17).

A decrease in MVELO in the PM reach direction occurred from precryotherapy (73.51 ± 15.63 mm/s) to postcryotherapy (65.75 ± 13.67 mm/s; $t_{23} = 5.61$, $P < .001$; 2 tailed). The mean difference in MVELO in the PM reach direction was 7.75 mm/s (95% CI = 4.09, 10.61), and the $\eta^2$ statistic indicated a large effect size (0.58).

The primary purpose of our study was to investigate the acute effects of a 15-minute cryotherapy application to the ankle joint on dynamic postural stability as quantified by performance on selected reach directions of the SEBT in elite-level collegiate male field-sport athletes. After the cryotherapy application, we noted a decrease in dynamic postural stability, as demonstrated by decreases in the ANT, PL, and PM reach directions of the SEBT, which was compounded by a decrease in MVELO in all reach directions.

# DISCUSSION

## Skin Temperature Changes

Temperature recorded over the ATFL and deltoid ligament differed across all 3 time points. As expected, we observed a decrease in the temperature recorded over the ATFL and deltoid ligament from time 1 to time 2. From time 1 to time 2, the mean decreases in temperature were 7.25°C over the ATFL and 6.87°C over the deltoid ligament. This finding is consistent with the results of other research[46–48] showing that skin temperature decreased with cryotherapy application. Whereas different, our temperature decreases were small when compared with those from other cryotherapy modalities: Love et al[46] observed decreases of 18°C, 26.4°C, and 19.5°C using an ice bag, ice massage, and cold-water immersion, respectively. The application of cryotherapy and, hence, the

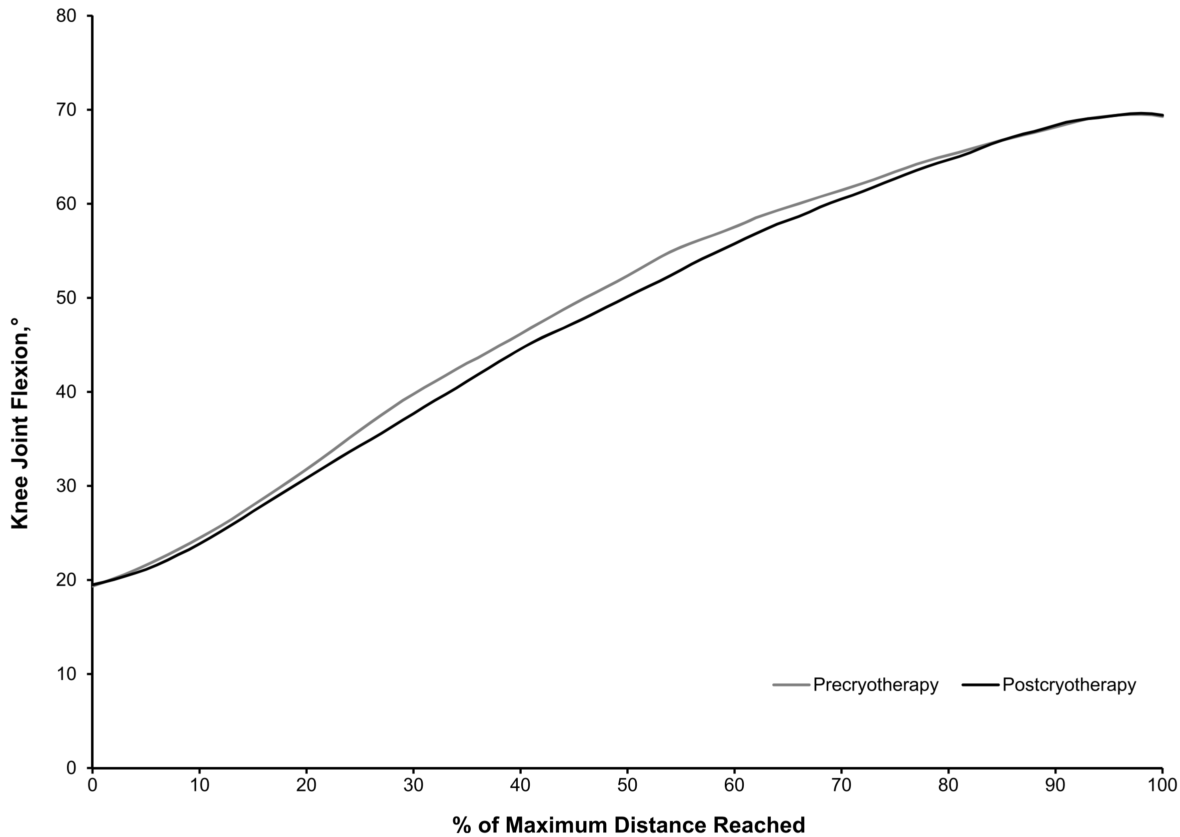


**Figure 5. Knee-joint flexion in the posterolateral reach direction of the Star Excursion Balance Test. 0 = Start of trial, 100 = point of maximum reach.**

reduction in skin temperature were associated with an acute decrease in postural-stability performance as evidenced by a decrease in selected SEBT reach-distance scores and an altered kinetic profile associated with the ANT and PM reach directions.

From a clinical perspective, the time required for an athlete's extremity to warm up after a cryotherapy application was important. The temperatures recorded over the ATFL were different at time 1 (29.18°C ± 1.18°C) and time 3 (24.13°C ± 2.18°C; $P < .001$) and consistent with the difference recorded over the deltoid ligament at time 1 (28.90°C ± 1.06°C) and time 3 (24.28°C ± 1.74°C; $P < .001$).

Our results are not too dissimilar from the observations of Kennet et al,[49] who reported that, even after 30 minutes of rewarming with 4 cryotherapy interventions (crushed ice, gel packs, frozen peas, cold-water immersion), the skin temperature of the ankle joint remained lower than that observed precryotherapy. In our study, the mean time to complete the postcryotherapy SEBT protocol was 12 minutes. Under the Gaelic Athletic Association,[50] the Fédération Internationale de Football Association[51] rules, and World Rugby laws,[52] the maximum half-time interval is 15 minutes. Therefore, if an ankle-joint cryotherapy intervention is applied during the half-time interval, the time available to allow the ankle joint to rewarm to ambient levels is likely insufficient. Consequently, an acute decrease in postural-stability performance may still be manifest when the athlete returns to participation after the half-time interval.

## Star Excursion Balance Test Reach Distances and Performance

Our results supported our hypothesis that a 15-minute cryotherapy application to the ankle joint would result in decreased reach distances on selected directions of the SEBT. We observed a reduction in all reach directions after cryotherapy application to the ankle joint and a decrease in the COMP reach-distance score. These lower scores indicated an acute decrease in dynamic postural-stability performance due to the cryotherapy application. Postural-stability testing is an integral component of clinical practice, so our results have important clinical implications. Decreased postural stability is a primary risk factor for lower limb injury, with researchers[25,53] reporting that athletes with poor static and dynamic postural stability were 2.5 to 6.5 times more likely to sustain lower extremity injuries. Ankle sprain is one of the most common lower limb injuries in field-sport and court-sport athletes.[54] Reduced postural stability is a sensorimotor deficit frequently associated with acute ankle sprain.[55] Therefore, minor sprains of the ankle joint already debilitate athletes' postural-stability performance. It is not unusual for physical therapists, athletic trainers, and sports medicine clinicians to administer cryotherapy to an athlete with a minor ankle sprain or contusion during a break in participation, such as a half-time interval. Our results suggested that the application of cryotherapy to the ankle joint is likely to further lessen dynamic postural stability. Consequently, clinicians need to be aware that postural-stability performance will likely be acutely decreased after a cryotherapy

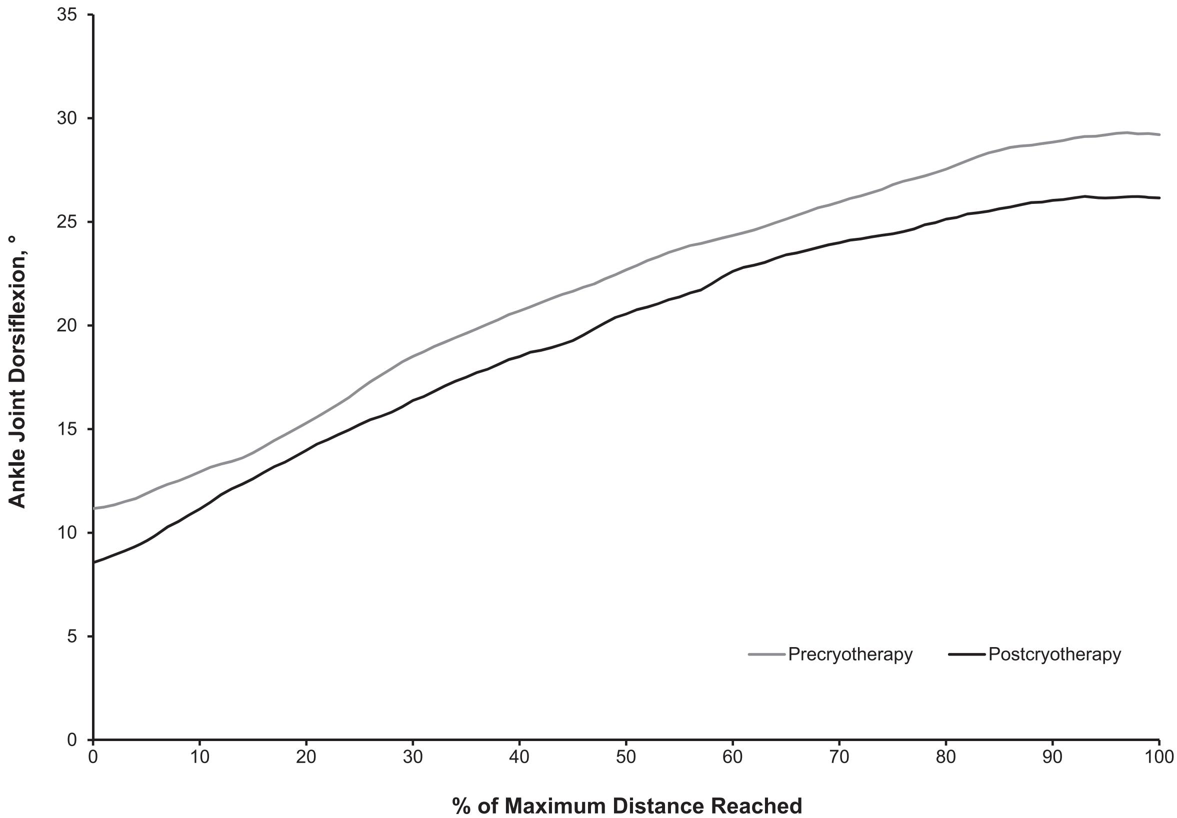


**Figure 6. Ankle-joint dorsiflexion in the posterolateral reach direction of the Star Excursion Balance Test. 0 = Start of trial, 100 = point of maximum reach.**

application to the ankle joint. Future research is warranted to investigate the influence of cryotherapy on the ankle joint and its influence on dynamic postural stability in a real-life injury scenario.

## Kinematics

Investigators[56–59] have shown that sagittal-plane motion of the hip, knee, and ankle joints is a strong indicator of reach distance on selected directions of the SEBT. Hoch et al[60] reported that for the ANT reach direction (mean = 79.0% ± 5.8%), ankle-joint dorsiflexion accounted for 28% of the variance in the reach distance. Basnett et al[61] found that ankle-joint dorsiflexion range of motion had the strongest relationship ($r = 0.55$) with the ANT reach direction of the SEBT, explaining 31% of the variance in reach distance and, thus, indicating that mechanical impairments in ankle motion can affect dynamic function during a balance task.

With respect to the ANT reach direction, Figures 1 and 3 demonstrate that, postcryotherapy, participants exhibited an increase in hip-joint flexion (mean difference across the reach direction = 3.8°) along with a reduction in ankle-joint dorsiflexion (mean difference across the reach direction = 1.16°). We hypothesize that these 2 observations could contribute to a decreased reach distance achieved in the ANT direction after cryotherapy. The finding of increased hip-joint flexion after cryotherapy application to the ankle joint was interesting. Fullam et al[36] noted that participants achieved a greater ANT reach distance on the SEBT than on the Y-Balance Test. They also showed that, while performing the ANT reach direction of the Y-Balance Test, participants demonstrated increased flexion of the hip joint. They theorized that increased flexion at the hip joint would result in a more anterior displacement of the participants' center of mass, which may limit their ability to use their center of mass to counterbalance the reaching leg. This, in turn, may limit their capacity to achieve a reach distance similar to that in the ANT reach direction of the SEBT.[36] We contend that the increased hip flexion postcryotherapy and decreased ankle-joint dorsiflexion could account for the decreased reach distance in the ANT direction after cryotherapy.

In the PM reach direction, participants were characterized by a reduced hip-flexed (mean difference across the reach direction = 3.9°), knee-flexed (mean difference across the reach direction = 1°), and ankle-dorsiflexed (mean difference across the reach direction = 1°) kinematic profile postcryotherapy that was not different (Figures 7–9). Similarly, in the PL reach direction, participants displayed a reduced knee-flexed (mean difference across the reach direction = 1.5°) and ankle-dorsiflexed (mean difference across the reach direction = 2.1°) kinematic profile postcryotherapy that was not different (Figures 4–6). In both the PM and PL reach directions, the distance achieved by the reaching limb critically depends on the sagittal-plane kinematics of the stance limb. An increase in sagittal-plane angular displacement at the hip (ie, increased flexion), knee (ie, increased flexion), and ankle (ie, increased dorsiflexion) joints while reaching in the PM or PL direction with the contralateral limb will effectively lengthen the reaching-limb's distance by decreasing the vertical position of the center of mass and pelvic position, thus inducing greater

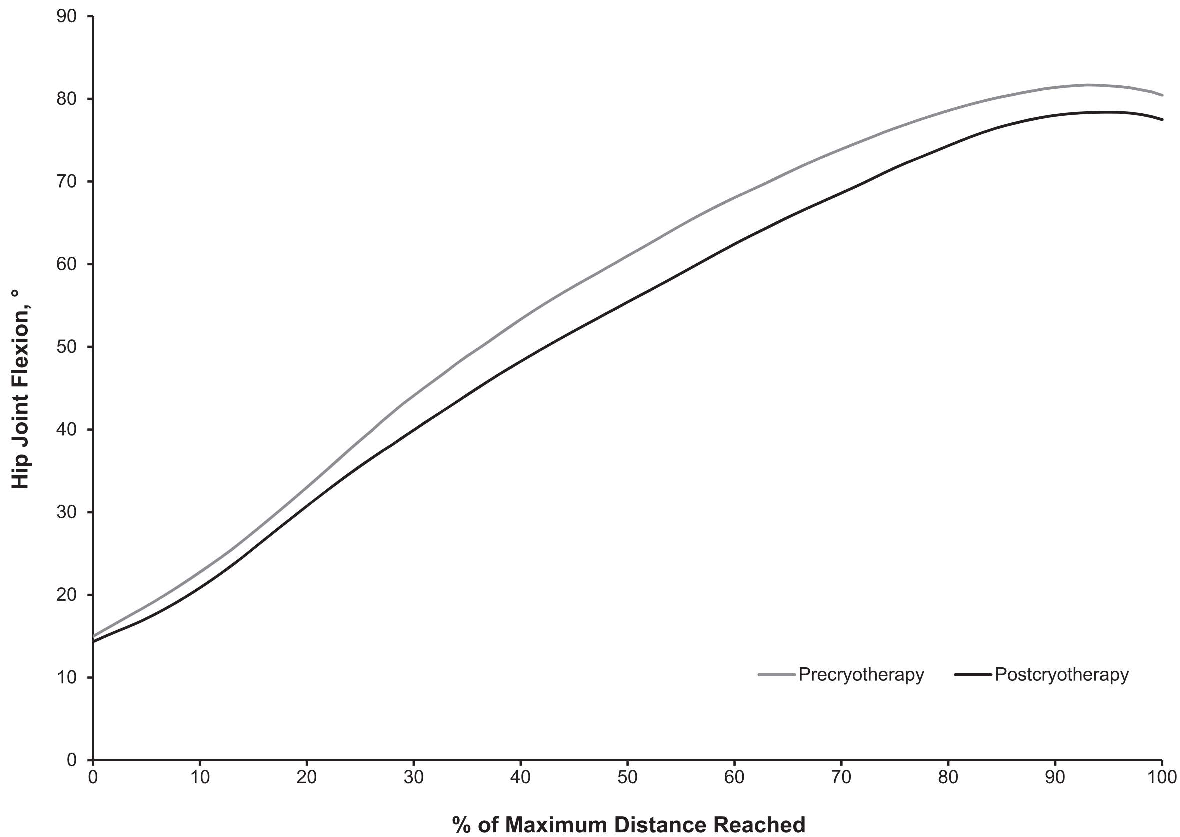


**Figure 7. Hip-joint flexion in the posteromedial reach direction of the Star Excursion Balance Test. 0 = Start of trial, 100 = point of maximum reach.**

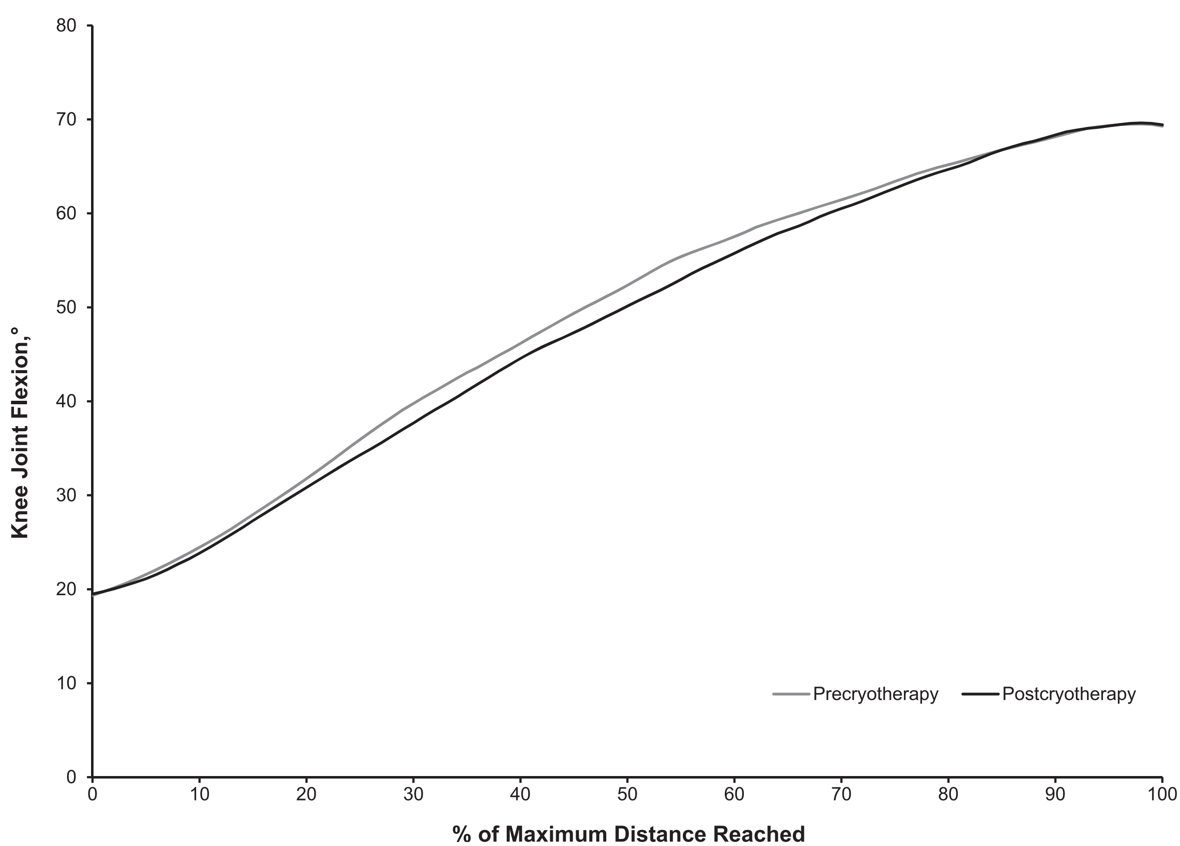


**Figure 8. Knee-joint flexion in the posteromedial reach direction of the Star Excursion Balance Test. 0 = Start of trial, 100 = point of maximum reach.**

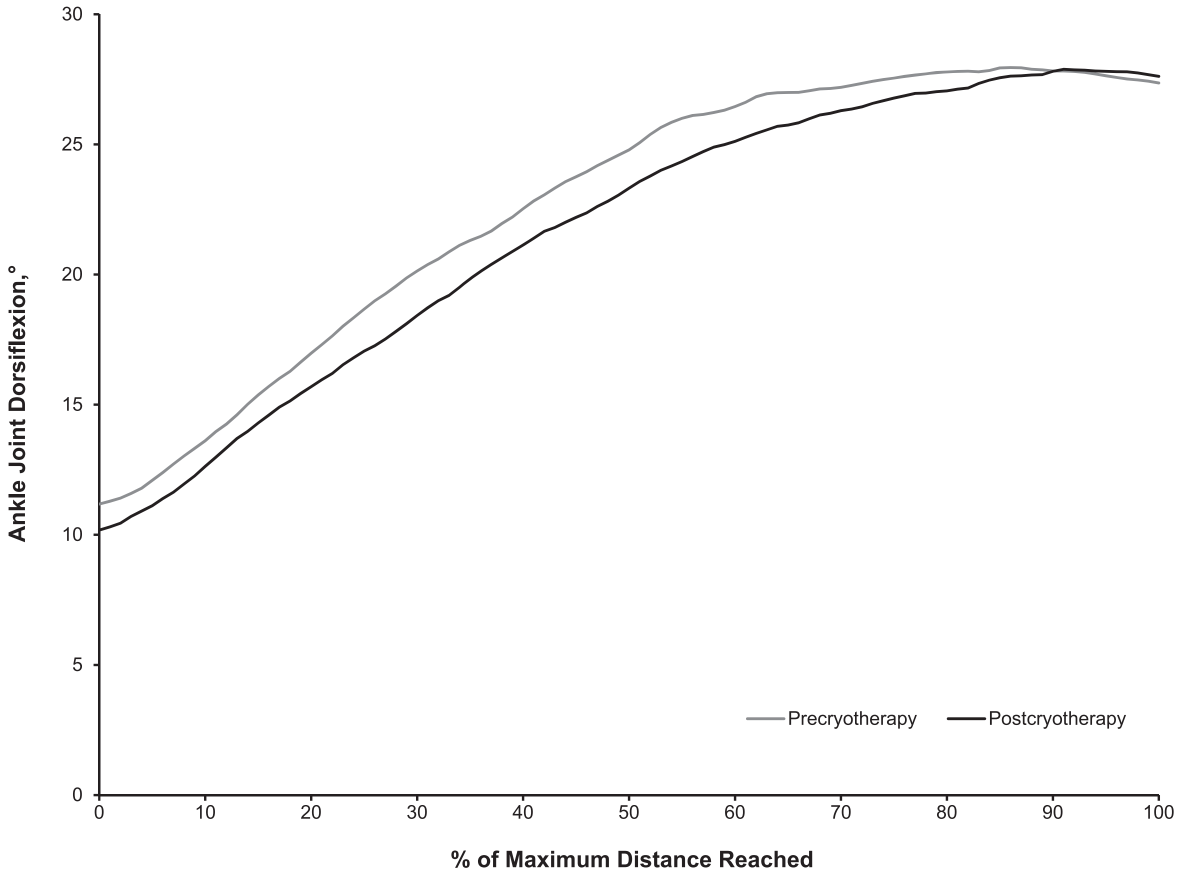


**Figure 9. Ankle-joint dorsiflexion in the posteromedial reach direction of the Star Excursion Balance Test. 0 = Start of trial, 100 = point of maximum reach.**

abduction of the reaching limb. In light of this biomechanical rationale, we hypothesize that, whereas not different, the decreased sagittal-plane kinematics postcryotherapy could account for the decreased reach distance in the PM and PL directions.

### Kinetics

The MVELO is the average velocity of the COP and can be used as an adjunct to clinical postural-stability analysis, giving clinicians and researchers a more comprehensive understanding of how cryotherapy to the ankle joint affects lower limb postural stability. We observed a decrease in MVELO in the ANT, PL, and PM reach directions after cryotherapy to the ankle joint, thus supporting the hypothesis that kinetic measures of postural stability would be altered. These findings suggest that applying cryotherapy to the ankle may result in a more deterministic movement pattern. Negahban et al[62] posited that more deterministic movements result in less flexibility of the neuromuscular control system to adapt to perturbations. Furthermore, Lamoth et al[63] suggested that variability in postural stability may be related to a greater ability to adapt to environmental constraints. Paterno et al[64] provided evidence to support the presence of a more deterministic postural-stability strategy in an injured group; single-legged dynamic postural-stability sway was decreased in the involved limbs of individuals with reconstructed anterior cruciate ligaments at the time of release to return to sport participation.[64]

Concerning our study, the cryotherapy-induced decrease in cutaneous temperature possibly negatively affected proprioceptors located in the ligamentous and musculotendinous structures surrounding the ankle joint. The performance consequence was manifested by reduced reach in the ANT, PL, and PM directions of the SEBT and a concomitant reduction in direction-specific MVELO. Therefore, clinicians should consider a rewarming protocol when returning an athlete to participation postcryotherapy to the ankle joint.

### Limitations

The key limitation of our study was that we studied non-injured elite-level collegiate male field-sport athletes. Therefore, the results must be interpreted as such and cannot be applied directly to an injured population. Future studies are required to determine the acute biomechanical effects of cryotherapy application to the injured ankle joint.

## CONCLUSIONS

A 15-minute cryotherapy application to the ankle joint decreased cutaneous temperature recorded over the ATFL and deltoid ligament. Furthermore, after cryotherapy application, decreased reach distances were achieved in the ANT, PL, and PM directions of the SEBT, with an associated decreased MVELO. Therefore, dynamic postural-stability performance was influenced negatively by a 15-minute cryotherapy application to the ankle joint. We contend that elite-level field-based athletes should undertake a rewarming period after cryotherapy to the ankle joint and before returning to participation to ensure they are not predisposed to injury due to decreased dynamic postural stability.

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*Address correspondence to Karl Fullam, BSc, School of Public Health, Physiotherapy & Population Science, University College Dublin, Belfield, Dublin 4, Ireland. Address e-mail to karl.fullam@ucdconnect.ie.*