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ORIGINAL RESEARCH

COMPARATIVE IMMEDIATE FUNCTIONAL OUTCOMES AMONG CRYOTHERAPEUTIC INTERVENTIONS AT THE ANKLE

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ABSTRACT

Purpose/Background: There is a lack of evidence detailing the immediate effects of different cryotherapy interventions at the ankle on functional outcomes such as balance and jumping tasks in a physically active population; therefore, the purpose of the present study is to compare the immediate effects of varied modes of cryotherapy applications to the ankle joint on Star Excursion Balance Test and vertical jump height performance. The authors hypothesized that cryotherapy would acutely decrease performance when compared to a control, and that concomitant compression would further hinder outcomes.

Methods: A crossover study was conducted in a controlled laboratory setting. Thirty (9 men, 21 women) participants (20.6 ± 1.0 years, 1.7 ± 0.1 m, 67.5 ± 11.7 kg) were enrolled. The independent variable was treatment mode; no ice, ice without compression and ice with compression. Dependent variables included center of pressure (COP) excursions, dynamic balance reach distances and vertical jump height for the dominant leg. Participants underwent three separate testing sessions separated by 72-hour rest intervals. The order of treatment and performance measures was randomized to prevent order effects. Normalized dynamic balance reach distances were assessed using the reliable modified Star Excursion Balance Test (SEBT). Center of pressure path length was assessed via a force platform during a single-legged static balance task under eyes-open and eyes-closed conditions. Relative vertical jump height was assessed using a single-legged vertical hop test. Group means and standard deviations were calculated by treatment mode. One-way analyses of variance with Tukey's post hoc test were used to calculate differences among treatment modes. $p < 0.05$ denoted statistical significance.

Results: No statistically significant differences existed for all the performance measures among treatment modes.

Conclusions: These findings suggest no immediate differences in lower extremity performance outcome measures between the respective treatment modes applied to the ankle in a young, healthy and physically active population. Additional investigation is warranted to study the related delayed effects of these interventions.

Levels of Evidence: III

Key Words: Ankle, balance, cryotherapy, functional performance.

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INTRODUCTION

Cryotherapy is one of the most commonly used therapeutic modalities in clinical physical rehabilitation settings.[1] Eliciting analgesia via cryotherapy is a goal often targeted by clinicians in treating patients suffering from musculoskeletal injury.[1] The analgesic response associated with cryotherapy is directly related to decreasing nerve conduction velocity of the nociceptor afferents, which is heightened as depth of cold penetration increases.[2] Cryotherapy has been estimated to reach to depths of approximately 2-4 cm in approximately 26 minutes in studies on the lower extremity;[3] however, the addition of compression via an elastic wrap is a common clinical practice that is suggested to increase the depth of penetration.[4] Consequently, cryotherapy also reduces nerve conduction velocity of mechanoreceptor afferents and muscle spindle sensitivity.[3] This results in a decrease in the amount of afferent sensory information reaching the central nervous system potentially impairing neuromuscular control and subsequent functional performance.[5-7] Such findings question the rationale for the clinical practice of applying cryotherapy prior to physical activity, such as sport.[8]

Unfortunately, a lack of evidence currently exists detailing the immediate effects of different cryotherapy interventions at lower extremity joints, specifically the ankle, on functional outcomes such as balance and jumping tasks in a physically active population. Though Evans et al[9] examined the effect of cryotherapy on agility measures in a cohort of athletic males, their study included the use of cold water immersion to the foot and ankle, which may not reflect more common modes of cold therapy interventions used in field settings and does not account for the potential influence of concomitant compression. Furthermore, the results of Evans et al[9] are limited in generalizability due to an apparent sex bias. Therefore, the authors attempted to address these limitations within the current experiment. Thus, the purpose of this research study was to investigate the immediate effects of cryotherapy applied to the ankle in the form of an ice pack, with and without compression, on objective performance measures, including postural control and vertical jump height in a healthy, young and physically active cohort of men and women. Based on previous findings,[2,5-7] it was hypothesized that cryotherapy would decrease performance measures when compared to a control condition of no ice. Additionally, it was hypothesized that ice with compression would elicit a greater decrease in performance when compared to ice without compression and a control condition.[2,4,10,11]

MATERIALS AND METHODS

Experimental Design and Participants

A crossover experimental design was utilized for this research study. Thirty (9 men and 21 women) young, healthy and physically active participants (Table 1) reported to the Athletic Training and Sports Medicine Research Laboratory for a total of three testing sessions lasting approximately one hour each over the course of approximately two weeks. Before participating in the study, all participants gave written informed consent per Institutional Review Board guidelines. Sessions were separated by a 72-hour rest interval. Participants completed the testing sessions under three different cryotherapy conditions applied to the ankle of the dominant leg: ice bag with compression (Figure 1), ice bag without compression (Figure 2) and no ice or compression. The ice bags were filled with crushed ice, weighed approximately 1.1 kilogram, and were applied directly to the skin on the anterior and posterior aspects of the ankle over the malleoli. The same investigator completed the ice application for all participants. The cryotherapy sessions lasted exactly 20 minutes. The sequence in which participants progressed through different conditions was randomized via the generation of random permutations using a statistical software package (Minitab 16, Minitab Inc., State College, PA) to prevent order effects.

Table 1. *Demographics and anthropometrics.*

	M ± SD
Participants	30
Sex (Men/Women)	9/21
Age (years)	20.6 ± 1.0
Height (m)	1.70 ± 0.1
Mass (kg)	67.5 ± 11.7
BMI (kg/m^2)	23.7 ± 4.7

Values are Mean ± Standard Deviation

Figure 1. *Ice with compression.*

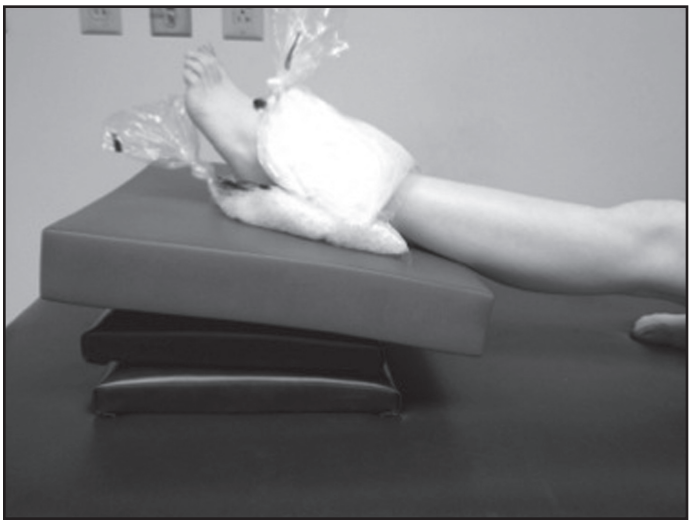

Figure 2. *Ice without compression.*

The necessary anthropometric measurements were taken at the first visit, which included height, mass, and bilateral leg length measures. Body mass index was calculated from height and mass data. Leg length was measured from the inferior most border of the anterior superior iliac spine to the apex of the medial malleolus with the participant in a supine position. Subsequent to the assigned treatment, participants' postural control and functional performance were measured via dynamic and static balance tasks, and a vertical hop task. The order of executed tasks was randomized in a similar manner as previously described in order to prevent order effects.

Dynamic Balance

The goal of the modified Star Excursion Balance Test (SEBT) is to reach as far as possible with one leg in each of the three directions while maintaining balance upon the opposite leg. Sufficient ankle, knee and hip ranges of motion are required to complete the task as well as adequate strength, proprioception and neuromuscular control. The SEBT is a functional screening tool that measures lower extremity reach while challenging the associated limitations of joint stability. Reliability of the SEBT has been investigated and reported in previous research studies.[12,13]

The modified SEBT was performed with the participant standing at the center of an outlined floor grid with eight lines extending at 45° angles from the center of the grid. The lines positioned on the grid were labeled according to the direction of excursion relative to the stance leg. The grid was constructed in an area using a protractor and 3 in (7.62 cm)-wide adhesive tape enclosed in a 182.9 cm by 182.9 cm square on a hard bare floor. Only three of the directions were used for this study, anterior, posteromedial and posterolateral, because these have been shown to be the most effective in detecting chronic ankle instability.[14] Participants were given verbal instructions and a visual demonstration. To become familiar with the task each participant performed four practice trials in each of the three directions.[15] To perform the SEBT the participant maintained a single-dominant leg stance while reaching with the non-dominant leg as far as possible along the appropriate direction. The participant contacted the furthest point possible on the line with a toe-touch using minimal pressure in order to ensure that stability is achieved through balance. An investigator manually measured the distance from the center of the grid to the touch point with a tape measure in centimeters. The same investigator took all reach measurements. Reach distance was marked and measured from the crosshair at the center of the star to the mark within 1 mm of precision. The mean of three reaches per direction was recorded and normalized to the non-dominant leg length and was represented as a percentage. Participants were given a 15-second rest interval between reaching trials, a one-minute rest interval between practice trials and data collection trials as well as a two-minute rest interval between changes in reach direction. The order of excursions

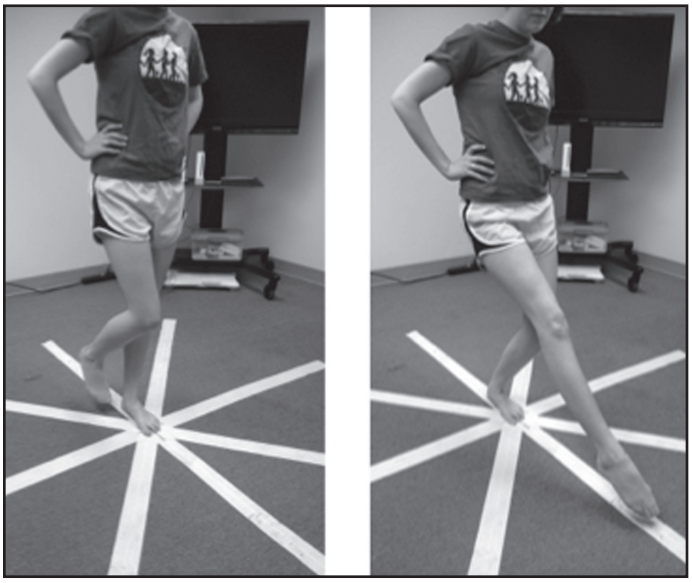

Figure 3. *Anterior balance reach task.*

performed was randomized in order to control for learning as well as order effects (Figure 3).

Trials were discarded and repeated if a participant did not touch the line with the reach leg while maintaining weight bearing on the stance leg, lost balance at any point in the trial or did not maintain initial and return positions for one full second. The trial was also discarded and repeated, if a participant touched down with the reach leg in a way that caused the reach leg to considerably support the body. Participants performed the task with hands upon hips. At no time were verbal cues or communication of encouragement directed to participants performing this testing.

Static Balance

The goal of the quiet stance single-legged balance task is to stand barefoot on one leg while maintaining balance for a 10-second period. Trials were conducted with eyes open and eyes closed. During the eyes-open condition, participants were instructed to stare at a black dot placed on the wall approximately 10 feet from the force-plate. The stance foot of the dominant leg was placed in the same position for each trial and was precisely positioned on the Accusway force platform (AMTI Corp., Watertown, MA).[16] The participant was instructed to stand as still as possible with their hands on their hips while keeping the non-dominant leg bent at a 45° angle and

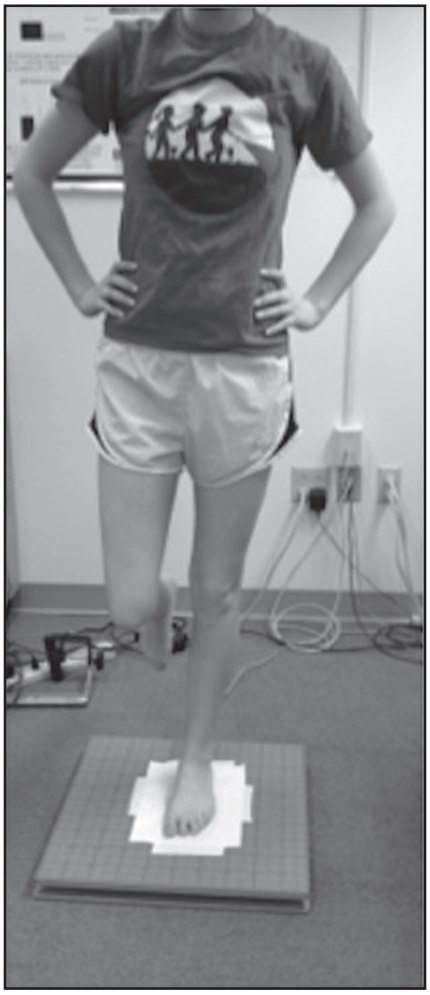

Figure 4. *Quiet standing balance.*

at the side (Figure 4).[16-18] If the participant touched the ground with the non-stance foot during the trial or if their hands were lifted off of the hips, the trial was disregarded and repeated. At no time were verbal cues or encouragement directed to participants. Center of pressure (COP) excursion measures, specifically path length (cm) and average velocity (cm/s), which are reliable measures of static balance[19,20] were recorded via Balance Clinic software (AMTI Corp., Watertown, MA). The mean COP and average velocity of the three trials for each condition were recorded. Participants were given one practice trial per condition and a 30 second rest interval between each of the three trials. A one-minute rest was given between conditions.

Single-Legged Vertical Hop

A VERTEC unit (Sports Imports Inc., Columbus, OH) was used to measure single-legged vertical hop

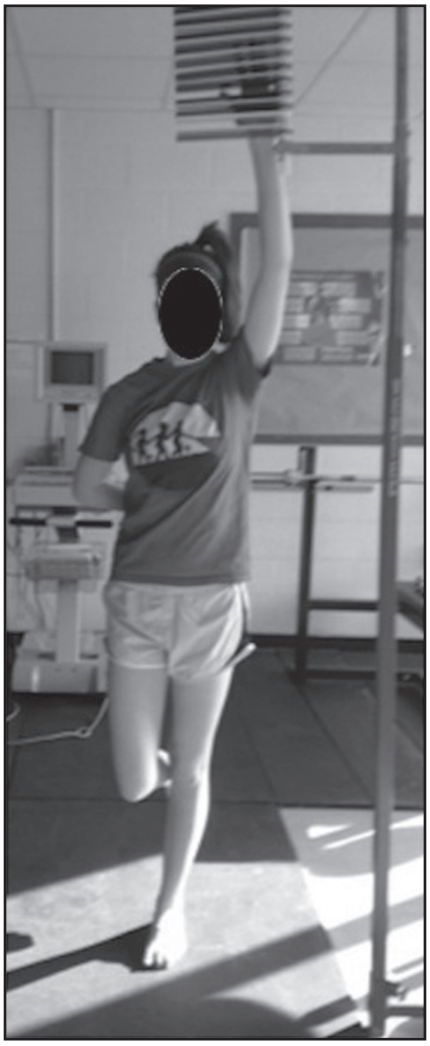

Figure 5. *Single-legged vertical hop.*

height. Participants stood next to the VERTEC on one foot of the dominant leg with the arm closest to the VERTEC raised overhead and their opposite arm behind their back.[21] Participants completed three practice trials with a minute rest interval between practice and measured jumps and a 30-second rest interval between measured trials. The participants' maximal reach was measured; the mean hop height of 3 trials was determined and the difference between the two values was calculated to find maximum hop height. The single-legged vertical hop has been used in a number of other studies examining functional performance post-cryotherapy[6,21,22] and is reported to closely simulate the functional stability that is encountered in sporting activities.[20] It also incorporates the power production required in dynamic propulsion tasks commonly performed in sports participation. (Figure 5).

Statistical Methods

Descriptive statistics, including group means and standard deviations were calculated for the dependent variables of interest. A one-way analysis of variance (ANOVA) was calculated to examine differences among the dependent variable means for the three conditions. Residual analyses were conducted to ensure the data met the necessary assumptions for ANOVA. An *a priori* alpha level of $p < 0.05$ denoted statistical significance. When indicated, Tukey's Honestly Significant Difference post hoc test was calculated to examine pairwise comparisons among the three conditions. A 95% simultaneous confidence interval (SCI) was used to denote statistically significant pairwise comparisons.

RESULTS

Residual analyses of the data set confirmed it met necessary assumptions for ANOVA.

Dynamic Balance

There were no statistically significant differences in normalized (by leg length) reach distances (anterior: $p = 0.568$; posteromedial: $p = 0.849$; posterolateral: $p = 0.499$) for the modified SEBT between conditions (Table 2).

Static Balance

There were no statistically significant differences in center of pressure excursions under eyes-open (path length: $p = 0.835$; average velocity: $P = 0.844$) and eyes-closed (path length: $p = 0.713$; average velocity: $P = 0.800$) conditions, among cryotherapy conditions (Table 3).

Functional Performance

There were no statistically significant differences in single-legged vertical hop height between conditions ($p = 0.610$) (Table 4).

DISCUSSION

The purpose of this study was to examine the short-term effects of cryotherapy applied to the ankle joint on dynamic and static balance, and functional performance. The authors hypothesized that ice applied to the ankle would decrease measures of balance as well as functional performance as measured by the vertical hop test due to altered position sense

Table 2. *Dynamic balance reach distance measures.*

Pairwise comparisons	%LL M ± SD	95% Simultaneous Confidence Interval (Lower Bound, Upper Bound)
Anterior		
No Ice vs:	75.1 ± 6.6	
Ice Without Compression	77.0 ± 6.6	(-2.877, 5.653)
Ice With Compression	75.1 ± 6.6	(-4.721, 3.819)
Ice Without Compression vs:	77.0 ± 6.6	
Ice With Compression	75.1 ± 6.6	(-6.104, 2.436)
Posteromedial		
No Ice vs:	103.2 ± 9.4	
Ice Without Compression	104.1 ± 12.4	(-7.36, 6.09)
Ice With Compression	103.2 ± 9.4	(-8.33, 5.12)
Ice Without Compression vs:	104.1 ± 12.4	
Ice With Compression	103.2 ± 9.4	(-7.70, 5.75)
Posterolateral		
No Ice vs:	94.8 ± 11.5	
Ice Without Compression	98.3 ± 10.1	(-4.85, 9.30)
Ice With Compression	94.8 ± 11.5	(-8.32, 5.83)
Ice Without Compression vs:	98.3 ± 10.1	
Ice With Compression	94.8 ± 11.5	(-10.55, 3.61)

M = mean, SD = standard deviation

and the nerve conduction velocity decrements associated with cryotherapy.[23] Furthermore, based on previous findings,[2] the authors hypothesized that compression added to a cryotherapeutic treatment would result in heightened deficiencies with the aforementioned measures. However, the current results indicated no decreases in dynamic and static balance or functional performance existed, regardless of the type of cryotherapeutic intervention.

Although few studies have examined the immediate effects of cryotherapy on dynamic balance the current results are similar to one previous investigation. Miniello et al[24] examined time-to-stabilization from a jump-landing task, as an index of dynamic balance, following a lower leg cold water-ice immersion treatment and found no associated deficiencies. In instances where the current results contrast with those of prior similar studies, related discrepancy may be attributed to differences in the experimental methods used. For example, the cryotherapeutic interventions in the current study were limited to the ankle joint, where as other investigations targeted muscle tissue.[21,22] As previously discussed, dynamic balance outcomes may differ based on the premise that joints and muscle tissue respond differently to cryotherapy, which may account for conflicting reports in the related literature. This concept may also serve as the basis for the lack of differences seen in static balance and functional performance outcomes in the current study.

Table 3. *Static balance, center of pressure excursions.*

Pairwise comparisons	Path Length (cm) M ± SD	95% Simultaneous Confidence Interval (Lower Bound, Upper Bound)	Average Velocity (cm/s) M ± SD	95% Simultaneous Confidence Interval (Lower Bound, Upper Bound)
No Ice, EO vs:	36.3 ± 10.2		3.62 ± 1.0	
Ice Without Compression, EO	34.3 ± 10.7	(-8.09, 4.84)	3.47 ± 1.1	(-0.806, 0.491)
Ice With Compression, EO	35.6 ± 10.6	(-7.14, 5.79)	3.56 ± 1.1	(-0.712, 0.585)
Ice Without Compression, EO vs:	34.3 ± 10.7		3.47 ± 1.1	
Ice With Compression, EO	35.6 ± 10.6	(-5.51, 7.42)	3.56 ± 1.1	(-0.554, 0.743)
No Ice, EC vs:	76.6 ± 18.7		7.53 ± 1.7	
Ice Without Compression, EC	75.9 ± 24.2	(-14.25, 12.94)	7.55 ± 2.3	(-1.290, 1.342)
Ice With Compression, EC	72.2 ± 22.9	(-17.95, 9.24)	7.22 ± 2.3	(-1.623, 1.009)
Ice Without Compression, EC vs:	75.9 ± 24.2		7.55 ± 2.3	
Ice With Compression, EC	72.2 ± 22.9	(-17.29, 9.89)	7.22 ± 2.3	(-1.648, 0.984)

M = mean, SD = standard deviation, EO = eyes open, EC = eyes closed

Table 4. *Single-legged vertical hop height.*

Pairwise Comparisons	Hop Height (cm) M ± SD	95% Simultaneous Confidence Interval (Lower Bound, Upper Bound)
No Ice vs:	24.8 ± 7.58	
Ice Without Compression	22.9 ± 8.13	(-4.85. 9.30)
Ice With Compression	24.1 ± 6.99	(-8.32, 5.83)
Ice Without Compression vs:	22.9 ± 8.13	
Ice With Compression	24.1 ± 6.99	(-10.55, 3.61)

M = mean, SD = standard deviation

Previous authors found similar results to the current study for static balance measures with cryotherapeutic interventions to the ankle and knee. Saam et al[27] and Kernozek et al[28] found that postural sway, a measure of static balance, was not affected by an ice bag application to the ankle when compared to a baseline or control. Furthermore, Rubley et al[29] found no significant differences in mediolateral and anteroposterior center of pressure path legth measures following a cold-water immersion of the lower extremity. Additionally, Thieme et al[30] examined the effects of cryotherapy on knee proprioception by examining joint angle reproduction and found cryotherapy did not significantly affect related joint position sense. Though proprioception or components of it, such as joint position sense and kinesthesia were not directly measured, the current outcomes, which suggest a crude indication of neuromuscular control capacity, seem to indicate that cryotherapy did not have a detrimental effect on the required proprioceptive information used to maintain dynamic or static balance.

In contrast with prior experiments, the current study revealed no decrements in functional performance. Several studies have demonstrated deficits in functional performance after cryotherapeutic interventions directed toward muscle tissue. Richendollar et al[21] studied three measures of functional performance and how they were affected by an ice bag application to the anterior thigh. The ice proved to be detrimental to the shuttle run, single-legged vertical hop and 40-yard sprint. Similarly, Fischer et al[22] found a decrease in functional performance on the shuttle run and single-legged vertical hop immediately after icing the hamstrings muscle group. Wassinger et al[7] reported complementary results when upon icing the shoulder joint and noting deficits in throwing accuracy. Conversely, Evans et al[9] found no associated decrease in agility task performance and an increase in ankle joint stiffness following cyrotherapy. Evans et al[9] attributed the lack of a detrimental effect on agility task performance to the fact that the ice was applied 8 cm above the lateral malleolus, which is below the large muscle groups of the lower leg.

The lack of deficits in balance or functional performance in the current study may be attributed to the fact that a joint was iced; while previous studies[21,22,25] demonstrating negative clinical effects have targeted muscle tissue. This observation may help resolve conflicting results of many comparable prior studies investigating a similar cryotherapeutic modality theme. Prior findings lend to the notion that cooling the tissues surrounding a joint[25,26] will affect proprioception differently than cooling muscle tissue.[21,22,25] For example, the application of cryotherapy to a joint has not been conclusively shown to alter joint position sense, which would theoretically lend to proprioceptive deficits.[7,30] Conversely, cooling a muscle inhibits muscle spindles, as well as adenosine triphosphate production and impairs calcium release[7] that may lend to muscle inhibition,[25,26] which potentially contributes to related balance and functional performance deficits. Altering the proprioceptive traits of the muscle spindles has been proposed as a foundation for the observations of functional performance decrements after bouts of stretching.[31] In contrast, Hopkins et al[26] noted that localized cooling of the ankle joint increased surrounding muscle activity, reflex amplitude and allowed for greater force production about the respective joint. Furthermore, Hopkins et al[25] reported an increase in peroneus longus activation that lasted approximately 60 minutes post-cryotherapy applied to the ankle joint. Consequently, Hopkins et al[25,26] proposed that the physiological mechanisms that underpinned their findings may be attributed to alterations in afferent input from the skin and joint receptors as well as altered supraspinal drive due to joint cooling.[32] For example, cryotherapy has been shown to increase joint and musculotendinous stiffness[33] as well as inhibit the golgi tendon organ for reflexive protection; thereby lending to heightened muscular performance about a joint as a secondary protective mechanism.[34] Thus, such physiological mechanisms may serve as a basis for the lack of balance and functional performance deficits noted in the current study,[28] and support the notion that cooling a joint elicits different physiological responses than cooling a muscle.[25,26]

The fact that no differences were observed in outcome measures when assessing the addition of compression with ice is also a noteworthy finding. Previous investigators have eluded to compression potentially increasing the depth of penetration for a cryotherapeutic modality such as ice,[2] which was assumed to result in heightened performance measure decrements. In

prior studies,[21,22] where muscle tissue was iced, further deficiencies in performance were noted after an ice bag was applied to the respective area with added compression when compared with no compression. However, the current study, which targeted cryotherapy to the ankle joint, reported no such differences. The basis for the current study's contrasting results for this variable, when compared to prior studies,[22,23] may again stem from the different responses elicited when icing a joint or muscle. Depth of penetration is dependent upon many factors, such as structural and material characteristics of the tissues being cooled, which include: thickness, density and water content of the respective skin, adipose and muscle being treated.[2] Other factors that affect depth of penetration include the local temperature gradient and treatment surface area in direct contact with the cryotherapeutic agent. The ankle joint does not have a considerable amount of thick and dense soft tissues that envelope the area as opposed to mid-body segments such as the thigh and shank, which possess the thick and dense muscle tissues overlaid with adipose. Compression and depth of penetration may be more relevant to the physiological changes in muscle than to a joint.

Clinical Implications

Based on the current findings, icing the ankle joint does not appear to detrimentally affect immediate dynamic and static balance or functional performance for the dominant leg in a healthy population. Furthermore, the results of functional performance assessments after the addition of compression to the ice application do not appear to differ with those seen after ice application without compression. These data may help clinicians make more informed decisions regarding icing before physical activity as commonly performed in sports medicine and rehabilitation. For example, cryokinetics, the application of ice to a painful joint before rehabilitative exercises, would not be considered contraindicated per the current observations; however, based on prior notations in the literature this may not apply to instances of icing a muscle where deficits have been reported.

Limitations

All participants in the present study had uninjured ankles. Since cryotherapy is indicated for acute injuries, the injury or inflammation present after injury may not make these results applicable to an injured population. Also, a relatively young participant cohort was studied; thus, responses may differ in an older population. Also, participants were recreationally active and more competitive participants could have responded differently. The current study was also limited to the immediate effects of ice on the dominant leg; however, continued study is necessary to determine the delayed effects and responses of the non-dominant leg. Moreover, surface and subcutaneous temperature were not measured; as such, definitive depths of penetration associated with the current cryotherapy applications could not be confirmed. Furthermore, it was not investigated if compensatory mechanisms at the knee, hip or trunk contributed to outcome measures we noted. Additionally, examiner bias may have existed as the result of not blinding.

CONCLUSIONS

In conclusion, the results of the current study demonstrated that cryotherapy was not detrimental to immediate measures of dynamic and static balance, nor functional performance as measured by a vertical hop task. Additionally, cryotherapy in combination with external compression did not decrease balance and functional performance more than cryotherapy alone. Based on these results, the authors propose that the immediate effects of cryotherapy applied to the ankle joint are not detrimental to lower extremity balance and performance, in the short term. Further research is warranted in order to examine the differential effects of icing muscle and joint(s) as well as the related long-term effects. Additional research should also include examining the Hoffman's reflex in response to cryotherapeutic interventions as well as comparing additional functional outcomes such as agility or shuttle running of the dominant as well as non-dominant leg.

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