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The Effect of Cold-Water Immersion on Running Mechanics

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ABSTRACT

International Journal of Exercise Science 12(1): 547-555, 2019. Cryotherapy is a common treatment used by athletes for rehabilitating acute injuries of a joint or muscle in order to accelerate recovery time and promptly return to play. Therefore, the potential effects of cryotherapy on performance and injury risk should be considered. The purpose of the current study was to investigate the effects of cold-water immersion on running mechanics. Fifteen healthy male and female participants (24.6 ± 5.74 years, 166.37 ± 7.67 cm, 71.72 ± 17.7 kg, 27.47 ± 7.55% body fat) were recruited for the study. Participants completed 10 running trials at a self-selected comfortable pace on a 15-meter runway before and after a 20-minute cold-water immersion treatment. The variables of interest included running velocity, ankle power, ankle angle at heel strike, peak ankle plantarflexion angle, and the ankle angle at the time of peak ankle power. Pre- to post-treatment values were compared using paired samples t-tests, $\alpha = 0.05$. Self-selected running velocity, peak ankle power, and ankle plantarflexion angle at heel strike decreased significantly (-0.13 m/s, $p = 0.004$; -53.69 Nm/s, $p = 0.011$; -2.17 degrees, $p = 0.007$, respectively) after cold-water immersion. Plantarflexion angle at the time of peak ankle power (p=0.461) and peak ankle plantarflexion angle ($p = 0.07$) were not different between pre- and post-treatment conditions. The observed changes in running velocity, peak ankle power, and plantarflexion angle at heel strike demonstrate that the cold-water immersion treatment may negatively affect performance and potentially influence injury risk. These effects on running mechanics may influence the decision for clinicians and athletes to utilize cold-water immersion immediately before physical activity.

KEY WORDS: Biomechanics, cryotherapy, ankle, lower extremity

INTRODUCTION

Cryotherapy is commonly utilized as a simple but effective treatment for pain due to acute musculoskeletal injuries, such as ankle sprains (1, 25), and is an indicated treatment during the acute stages of inflammation to accelerate healing (3). Various forms of cryotherapy exist, including cold packs, ice massage, cold compression, and cold-water immersion. When available, cold-water immersion is preferred due to cooling efficiency (13, 15, 21) and the ability to treat peripheral edema through hydrostatic pressure (3). The use of cryotherapy on an acute musculoskeletal injury may result in a faster return to play and a reduced risk of secondary hypoxic injury (12). Although a quick return to play is desirable, the goal of acute injury management is to safely treat the athlete while avoiding a heightened risk of injury or decrease in performance.

Ankle injuries are common in sports, accounting for up to 14% of all sports related injuries, with 81% of those ankle injuries being ligamentous ankle sprains (9). The average return-to-play timeline for ankle sprains has been estimated at 1 to 3 days, however, up to a 25% of athletes will return to play on the same day (16). As such, any effects of cryotherapy may remain when the athlete returns to play. Cryotherapy slows nerve conduction velocity of both sensory and motor neurons, thereby altering muscle force production and firing patterns (1, 11). These effects have the potential to alter movement patterns, thus potentially influencing injury risk and running performance.

Previous research investigating movement after cold water immersion suggests that there is not an influence on joint loading (10). However, in this research running velocity was constrained, which may influence running mechanics. Without constraining velocity, researchers have found that sprinting velocity in a 40-yard dash remained significantly slower for up to 22 minutes after cryotherapy (20). In practical application, an athlete's velocity will not be constrained following cold-water immersion, thus changes in running mechanics as a result of cryotherapy may be related to decreased velocity. In addition, cold water immersion has been shown to decrease concentric muscle strength (27) and decrease muscular power after a muscle has been cooled (2, 4, 18). Cryotherapy has also been associated with decreases in task performance, which was further exacerbated when the task was performed at a higher velocity (19, 22). Therefore, research concerning the effect of cryotherapy on running movement analysis should allow for self-selected running velocities.

In addition to potential performance considerations, cryotherapy may influence an athlete's propensity for injury. Cryotherapy may slow nerve conduction velocity, thereby altering muscle force production and firing patterns (1). Cold-water immersion has been shown to adversely affect muscle activation (24), which may influence musculature that is important in protecting against lateral ankle sprains, such as the peroneus longus (21). Timely activation of the ankle musculature can protect against ankle inversion sprains (5), thus a decreased activation of these muscles may increase an athlete's risk of inversion ankle sprain. Indeed, previous research has linked altered kinematics with ankle sprain occurrence (7, 8, 14). As athletes utilize cryotherapy to return to activity after a minor injury, it is important to directly assess the impact of treatment on gait mechanics to determine if the risk of ankle sprain is heightened.

Therefore, the purpose of this study was to investigate the effects of cold-water immersion on running mechanics. Specifically, the current study investigated changes in self-selected running velocity, peak plantarflexor power, ankle angle at heel strike, ankle angle at the time of peak plantarflexor power, and peak ankle plantarflexion angle. We hypothesized the cold-water immersion would decrease the running velocity, plantarflexor power, and joint angles analyzed in the current study.

METHODS

Participants

Using G*POWER software (v. 3.1, Universitat Kiel, Germany), we determined that a sample size of 11 was needed for a power of 0.80, with an effect size of 0.84 (5), and an alpha level of 0.05. Fifteen healthy and recreationally active male and female participants (24.6 ± 5.7 years, 166.4 ± 7.7 cm, 71.7 ± 17.7 kg, 27.5 ± 7.6% body fat) were recruited for the study. Recreationally active individuals were chosen to be in agreement with a similar study observing the effects of cold-water immersion on running mechanics (10). The study was approved by the Institutional Review Board at the University of Nevada, Las Vegas (protocol #1054133) and participants provided written informed consent prior to participation. The Physical Activity Readiness Questionnaire (PAR-Q) was used to determine the presence of health problems that would limit the safety of participation. Additionally, individuals were excluded from the study if they had sustained a lower body injury within six months prior to participation. A lower body injury was defined as musculoskeletal pain which kept the individual from participating in physical activity for more than a week, with or without a medical diagnosis. Participants were also excluded from the study if they had a history of lower extremity surgery due to a musculoskeletal injury, or if they had a known cold allergy.

Protocol

Anthropometric data including each participant's age, height, mass, and body fat percentage (inBody 770, Cerritos, CA) were recorded. Participants were asked to complete a five-minute warm up either on a treadmill or outdoors at a self-selected pace. Retro-reflective markers were placed bilaterally on the hips, thighs, legs, and feet. For the collection of running trials, participants were asked to run at a comfortable pace along the 15-meter runway in a laboratory equipped with ten 3D motion capture infrared cameras (200 Hz, Vicon, Oxford, UK). Kinetic data were collected using three force platforms (1000 Hz, AMTI, Watertown, MA), which were embedded into the runway. Velocity was measured using photoelectric timing gates placed four meters apart on either side of the force platforms, though participants were not informed of their running velocity. Participants ran ten successful trials before cold-water immersion to establish a no-treatment baseline. Full contact of the dominant foot on the force platform, without targeting, was considered a successful trial. To prevent targeting, which occurs when a participant alters their movement to intentionally strike the force platform, the location of the force platforms was not revealed to participants.

Following baseline measures, markers were removed from the dominant lower leg, which was then immersed in cold water. The water temperature was maintained at 10-12 °C (approximately 50 °F) for the duration of the twenty-minute treatment. Water temperature was recorded every five minutes and ice was added as necessary to maintain the desired temperature. The participant's skin temperature was recorded using an infrared thermometer (Lasergrip 1080, Etekcity, Anaheim, CA) before and after the treatment and in five-minute increments during the treatment. The skin temperature was taken over the soft tissue approximately one inch proximal and medial to the lateral malleolus. After the treatment, skin temperature was recorded, markers were replaced, and an additional skin temperature was recorded prior to running. Participants were again instructed to run at a comfortable velocity and complete ten additional successful trials. Skin temperature was measured after the tenth successful trial.

Statistical Analysis
Marker trajectories were labeled, and gaps were filled in Nexus (v. 2.3, Vicon, Oxford, UK) with a maximum gap fill of 25 frames. Kinetic and trajectory data were filtered using a low-pass, fourth order, zero lag Butterworth filter with cutoff frequencies of 50 Hz and 10 Hz, respectively. Data were exported to Visual3D (v .6, C-Motion, Germantown, MD) for calculation of target variables. Values for each of the variables were averaged across trials for each collection time-point. The variables of interest were analyzed using SPSS software (v. 24, IBM, Armonk, NY). Pre- and post-intervention values were compared using paired samples t-tests with alpha levels set to 0.05 *a priori*. As a change in running velocity may lead to altered running mechanics, a follow-up statistical analysis was completed to assess velocity as a covariate. A univariate analysis of covariance (ANCOVA) was conducted to control for running velocity with alpha levels set to 0.05 *a priori*.

RESULTS

Three of the five variables were influenced by the cold-water immersion treatment (Table 1). Self-selected running velocity (p = 0.004), peak plantarflexor power (p = 0.011), and ankle angle at heel strike (p = 0.007) decreased significantly between the conditions. Ankle angle at peak plantarflexor power (p = 0.461) and peak plantarflexion ankle angle (p = 0.070) did not demonstrate a significant difference between the two conditions. After adjusting for running velocity with the univariate ANCOVA, there were no statistically significant differences in any variables (p > 0.05).

Table 1. Effects of cold-water immersion treatment on variables of interest.

	Pre-Treatment	Post-Treatment	*P* value
Self-selected Running Velocity (m/s)	2.92 ± 0.49	2.79 ± 0.49	.004*
Peak Plantarflexor Power (Nm/s)	580.52 ± 167.10	526.83 ± 145.43	.011*
Ankle Angle at Heel Strike (°)	9.99 ± 4.71	8.18 ± 5.18	.007*
Ankle Angle at Peak Plantarflexor Power (°)	13.66 ± 4.08	14.04 ± 3.82	.461
Peak Plantarflexion Angle (°)	17.00 ± 7.37	15.55 ± 6.38	.070

All values are listed as mean ± SD. *indicates significance at p<0.05.

During immersion, water temperature was maintained between 10-12 °C (11.1 ± 0.2 °C). Figure 1 displays the average temperatures at each time point during and after the treatment. Skin temperature decreased in the first five minutes of cold-water immersion (Figure 1) and remained below baseline for the remainder of the study. Following treatment, it took approximately two minutes to re-adhere the markers prior to running. Skin temperature was measured at both post-treatment and post-marker placement. On average, the skin temperature at the end of treatment was 12.1 °C and rose to 20 °C when post-treatment trials started. The skin temperature increased to 24.4 °C after running trials.

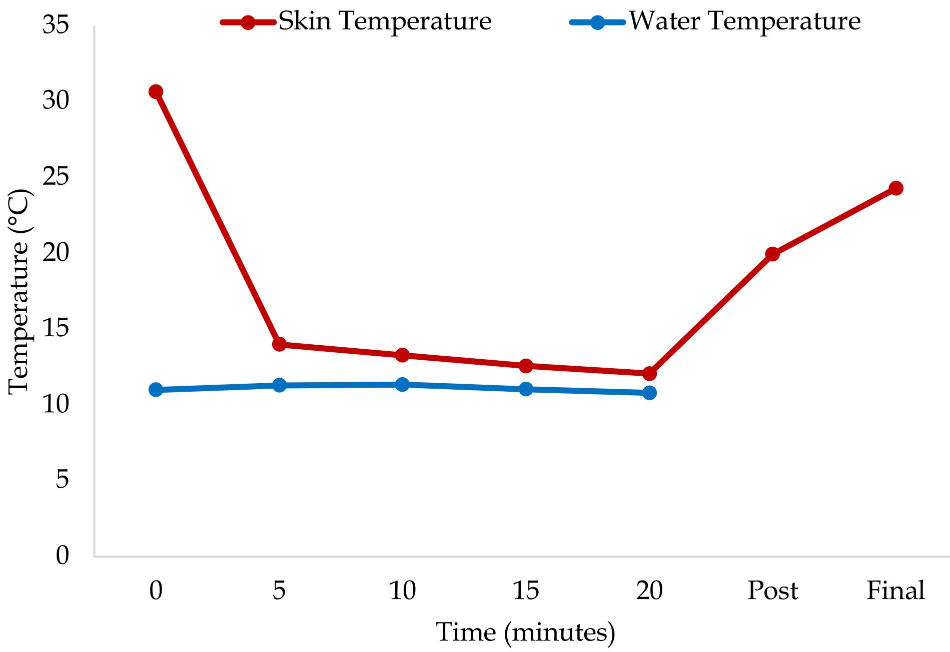

Figure 1. Skin and water temperature as recorded throughout the treatment duration. The vertical axis represents the recorded temperature in Celsius, and the horizontal axis represents the time at which the temperature was measured. The solid red line represents the skin temperature, and the solid blue line represents the water temperature. In addition to 5-minute increments throughout treatment, skin temperature was also measured after adhering the markers (Post), and again after the last post-treatment trial was completed (Final).

DISCUSSION

The purpose of the current study was to investigate the effects of cold-water immersion on running mechanics. We hypothesized that cold-water immersion would lead to decreases in running velocity, peak plantarflexor power, and ankle angles during running, thereby decreasing performance. The results for self-selected running velocity, peak plantarflexor power, and ankle angle at heel strike supported this hypothesis, while results for peak plantarflexion ankle angle and ankle angle at peak plantarflexor power did not support this hypothesis. These results indicate that cold-water immersion can alter running mechanics at the ankle. It is important to understand how these results may influence physical performance and injury risk if cold-water immersion is to be used as a treatment for athletes intending to return-to-play quickly.

In the current study, self-selected running velocity was assessed as a metric of performance. The only instruction provided to participants was to run at a comfortable pace. Without influence by the researchers, participants ran at a slower velocity after the cold-water immersion. A decrease in running velocity suggests participants selected a new comfortable pace because of the cold-water immersion. Associated with this decrease in running velocity, we also observed a decrease in peak plantarflexor power and ankle angle at heel strike. While a primary aim of the study was to determine if cold-water immersion affected self-selected running velocity, it is also important to consider the subsequent effect of a decreased running velocity on plantarflexor power and ankle angle at heel strike. We examined this effect in our statistical analysis by utilizing a univariate analysis of covariance (ANCOVA) with running velocity as the covariate. As expected, the significant decrease in velocity accounted for the decreases in plantarflexor power and ankle angle at heel strike. While a previous study determined that cryotherapy had no effect on mechanics at the ankle, these results were obtained while participants ran at a controlled velocity (10). The current study allowed participants to choose their pace, much like athletes would outside of the laboratory.

A decrease in self-selected running velocity may indicate altered performance. The observed decease in ankle propulsive power during late stance corresponded with decreases in running velocity following cold-water immersion. As plantarflexor power provides propulsion during late stance, decreases in this measure are coupled with decreases in running velocity, and may therefore indicate performance decrements. This decrease in propulsive power, along with decreases in concentric muscle strength (27) and decreased muscular power (2, 4, 18) occurred in previous cryotherapy research studies, supporting the notion that overall performance may be influenced by the use of cryotherapy. Similar effects were observed in a study which demonstrated that a 20-minute lower extremity whirlpool treatment (10 °C) led to increased 40-yard dash times, decreased countermovement vertical jump height, and decreased ankle dorsiflexion (20). Limited or reduced ankle range of motion, along with decreased power as observed in the current study, prohibits the spring-like action at the ankle that is needed for propulsion during running.

Along with performance effects, the effect of cold-water immersion on running mechanics and potential altered proprioception may pose an increased risk of injury. Inversion ankle sprains involve damage to the anterior talofibular ligament, (6, 24) which experiences the most strain when the ankle is plantarflexed and inverted (23, 24). Furthermore, forceful inversion while the ankle is plantarflexed is a common mechanism of injury with inversion ankle sprains (29). The average angle at heel strike in the current study before cryotherapy treatment was 9.99 ° of dorsiflexion, which agrees with previous research that has shown heel strike angles of 10.8 ° (26) and 13-15 ° of dorsiflexion. However, after cryotherapy, the ankle angle at heel strike was more plantarflexed. Although this change was statistically significant, the clinical implications of a two-degree change is unknown. If we anticipate this change in ankle angle to be clinically important, it may place athletes returning to activity following cryotherapy at a higher risk of inversion ankle sprain.

In addition to observed changes in gait mechanics, participants also expressed that plantar sensation was reduced while running. Though this information is anecdotal, we speculate that some of the changes we observed were related to changes in plantar surface sensation. It is possible that altered sensation in the foot decreased participants' confidence in their ability to run following the cold-water immersion. A decrease in confidence may contribute to a decreased self-selected running velocity. It has been suggested that when cold is used to alter sensation on the foot, the center of pressure is shifted to the side that is least impaired (17). While this may not pose a significant risk in a laboratory, where participants have a stable and consistent surface to run on, athletes performing outdoors often run on uneven and unpredictable surfaces.

Additionally, if the center of pressure is shifted laterally due to cold-water immersion, the risk of ankle sprains may be amplified (28), particularly if an athlete is in a more plantarflexed position as well. This suggests a need for future studies to investigate changes in center of pressure of the plantar surface of the foot following a cold-water immersion treatment.

One limitation of the current study is the lack of a questionnaire or scale to determine sensation or confidence levels of the participants. Future research regarding the effects of cold-water immersion should collect self-reported sensation and confidence levels throughout testing to determine the extent to which these variables may influence movement. Additionally, the mechanism of ankle sprains involves tri-planar movement, and the current study only analyzed movement in the sagittal plane. The results of this study provided information regarding the immediate effect of cold-water immersion on running mechanics in a healthy, recreationally-active population. Further research examining the effect of cold-water immersion in an injured athlete population over a longer period of time will allow for the development of return-to-play protocols and timelines that may be implemented in a clinical setting.

The results of this study suggest cold-water immersion may adversely impact performance in athletes wishing to return to physical activity. Significant decreases in self-selected running velocity, peak plantarflexor power, and ankle angle at heel strike were observed after a 20-minute cold-water immersion treatment. These effects on running mechanics and overall performance may influence the decision for individuals to utilize cold-water immersion immediately before physical activity. Clinicians should be aware of the potential negative effects of cold-water immersion before making a return-to-play decision.

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