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Effect of knee joint cooling on the electromyographic activity of lower extremity muscles during a plyometric exercise

Stefan Schmid [a,*], Marilyn Moffat [b], Gregory M. Gutierrez [b]

[a] *Bern University of Applied Sciences, Health Division, Research and Development Physiotherapy, Murtenstrasse 10, 3008 Bern, Switzerland*
[b] *New York University, Steinhardt School of Culture, Education, and Human Development, Department of Physical Therapy, 380 Second Ave., 4th Floor, New York, NY 10010, USA*

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ABSTRACT

During sporting events, injured athletes often return to competition after icing because of the reduction in pain. Although some controversy exists, several studies suggest that cryotherapy causes a decrease in muscle activity, which may lead to a higher risk of injury upon return to play. The purpose of this study was to investigate the effect of a 20-min knee joint cryotherapy application on the electromyographic activity of leg muscles during a single-leg drop jump in twenty healthy subjects, randomly assigned to an experimental and a control group. After the pre-tests, a crushed-ice bag was applied to the knee joint of the experimental group subjects for 20 min, while the control group subjects rested for 20 min. All subjects were retested immediately after this period and retested again after another 20 min of rest. Average electromyographic activity and ground contact time were calculated for the pre- and post-test sessions. Decreases in electromyographic activity of the lower extremity musculature were found in pre-activation, eccentric (braking), and concentric (push-off) phases immediately after the icing, and after 20 min of rest. The results lend support to the suggestion that cryotherapy during sporting events may place the individuals in a vulnerable position.

1. Introduction

Cryotherapy is often used as an immediate treatment method to relieve the acute pain of soft tissue injuries (Bleakley et al., 2004). Other known effects include decreases in edema, inflammation, blood flow, metabolic rate, intramuscular temperature, hypertonicity, and nerve conduction velocity (NCV) (Enwemeka et al., 2002). Controversial evidence surrounds the question of how cryotherapy affects muscle activity. During sporting events, injured athletes often return to competition after a cryotherapy treatment because of the reduction in pain.

It has been suggested that cryotherapy produces a decrease in muscle activity which may lead to a higher risk for re-injury when athletes return to competition after a treatment. This statement is based on investigations that showed negative effects on: NCV (Algafly and George, 2007); physical performance during maximal high-intensity functional tasks (Cross et al., 1996; Fischer et al., 2009; Kinzey et al., 2000; Richendollar et al., 2006); electromyographic (EMG) activity of leg muscles during the shortening phase of a maximal rebound jump (Oksa et al., 1997); joint position sense (proprioception) of the ankle and knee joints (Hopper et al., 1997; Uchio et al., 2003); and medium latency reflex response (increase in delay) (Grey et al., 2001). The results of these studies suggest that cryotherapy decreases the activity of the neuromuscular system, and although athletes may feel ready to return to competition after icing, motor performance may be impaired and the individual may be more vulnerable to injury.

In contrast, other studies have shown no clinically significant effect or even a positive effect of cryotherapy on muscle activity (Atnip and McCrory, 2004; Hopkins and Stencil, 2002; Melnyk et al., 2006; Pietrosimone et al., 2009; Rubley et al., 2003; Tremblay et al., 2001). These results are based on evaluations of the effect of cryotherapy on: stretch reflex responses of the hamstring muscles (Melnyk et al., 2006); weight discrimination using the quadriceps muscle (Tremblay et al., 2001); ankle joint kinematics (Atnip and McCrory, 2004); EMG activity of the rectus femoris and vastus lateralis muscles during a knee extension maximal voluntary isometric contraction (MVIC) (Pietrosimone et al., 2009); and soleus function, in terms of the Hoffmann reflex and peak plantar flexor torque (Hopkins and Stencil, 2002). Rubley et al. (2003) found negative effects but concluded that the effects had little significance in clinical practice. They investigated the effect of cryotherapy on sensation and isometric-force variability. The outcomes showed a reduced sensation of pressure, greater isometric-force variability, and decreased target accuracy. Several authors concluded that cryotherapy does not increase the risk for re-injury or may have a positive effect on the athlete when returning to competition after treatment (Atnip and McCrory, 2004; Melnyk et al., 2006; Rubley

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[*] Corresponding author. Address: Berner Fachhochschule, Gesundheit, aF&E Physiotherapie, Murtenstrasse 10, 3008 Bern, Switzerland. Tel.: +41 31 848 3796.
E-mail address: stefanschmid79@gmail.com (S. Schmid).

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et al., 2003). Hopkins and Stencil (2002) even recommended the use of joint cooling prior to activity and rehabilitation. However, the authors mentioned that they did not find enough evidence to make a tangible conclusion. Comparing the results of the different studies, it appears that the clinical relevance of the effect of cryotherapy on muscle activity strongly depends on type and intensity of the movement task. All studies involving reflexive and/or high-intensity tasks (plyometrics) revealed decreases in motor performance. However, none of the studies which found no or even positive effects of cryotherapy on functional performance involved a plyometric task.

In sports like soccer, volleyball, basketball, sprinting, high jumping, and long jumping, athletes use powerful plyometric movements, such as jumping and running. Unfortunately, the effects of cryotherapy on the electromyographic activity of leg muscles during these high demand plyometric tasks are not known. This information would provide a greater understanding of muscle performance during plyometric tasks and would provide a basis for further research on the avoidance of injury or prevention of re-injury during competition.

The current study aimed to investigate the direct effect of knee joint cooling on the muscular activity during a high-intensity plyometric exercise (single-leg drop jump). We hypothesized that the EMG activity of the lower extremity rectus femoris (RF), vastus medialis (VM), vastus lateralis (VL), biceps femoris (BF), medial head of gastrocnemius (MG), tibialis anterior (TA), and peroneus longus (PL) muscles during the plyometric exercise would significantly decrease after a 20 min cryotherapy application. In addition, we hypothesized that the effects of cooling would persist after another 20 min of rest after the cryotherapy treatment.

2. Materials and methods

2.1. Subjects

Twenty healthy males and females (Table 1), who were between 23 and 40 years of age and had full range-of-motion and normal strength in their lower extremities, were recruited to participate in this randomized controlled trial. All subjects were free of any history of orthopedic injury, had no musculoskeletal, neuromuscular, or cardiopulmonary diseases, disorders, or conditions within the last year, and had no history of surgery to their lower extremities. They were also free of any alcohol, drug, or caffeine intake that might have affected motor performance for at least 24 h prior to the experiment. Further, the subjects were non-smokers, were not suffering from cold hypersensitivity, had a normal dorsalis pedis pulse, and had normal sensation in the lower extremities. All subjects were able to perform a single-leg drop jump from a drop height of 30 cm (Fig. 1). Subjects were randomly assigned to a group using a randomized list and only became aware of their group assignment following the pre-test (once the ice was prepared for them). The room temperature and lighting remained constant for all subjects during the test. The laboratory was clean and free from extraneous noise. The experimental protocol had been approved by the University Committee on Activities Involving Human Subjects and all subjects gave informed consent.

Table 1
Subject demographics.

	Experimental group (ice)	Control group (no ice)
Total subjects	10	10
Male subjects	8	5
Female subjects	2	5
Age (mean ± SD), y	28.7 ± 5.5	28.7 ± 4.0
Height (mean ± SD), m	1.78 ± 0.1	1.72 ± 0.1
Weight (mean ± SD), kg	76.34 ± 11.8	67.04 ± 11.9
Right dominant leg	9	8
Left dominant leg	1	2

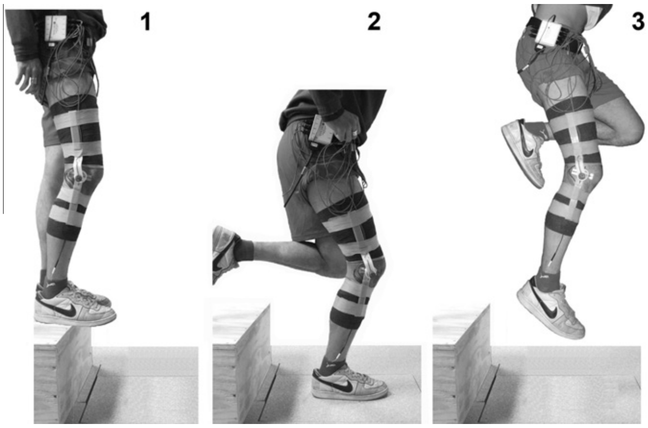

Fig. 1. Drop jump procedure: (1) starting-position; (2) landing on the force plate; and (3) jumping off vertically.

2.2. Instrumentation

2.2.1. Force plate and electrogoniometer

A multi-component force plate system (Kistler Type 9286A, Winterthur, Switzerland) was used to measure the ground reaction forces (GRF) during the jumps. The signal was collected at a sampling rate of 1 kHz and amplified in a range of 5 kN per channel (Kistler External Control Unit Type 5233A, Winterthur, Switzerland). A custom electrogoniometer that was attached to the lateral side of the knee joint of the dominant leg (see below) was used to measure the knee angle during the jumps.

2.2.2. EMG

The EMG activity of the lower extremity muscles (VM, VL, RF, BF, MG, TA, and PL) was measured using an eight-channel surface EMG system (Bagnoli-8, Delsys, Inc., Boston MA, USA). After skin preparation (shaving, gently scrubbing, and cleaning with alcohol), the bipolar surface electrodes [DE 2.1 Single Differential Surface EMG Sensor, Delsys, Inc., Boston MA, USA; Sensor Contacts – 2 silver bars, 10 mm long × 1 mm diameter; Contact Spacing – 10 mm; CMRR – 92 dB (typical), 84 dB (minimum)] were placed over the motor point of each muscle on the dominant leg (Perotto et al., 1994). The ground electrode was attached to the lateral malleolus of the same leg. The EMG signals were acquired at a sampling rate of 1 kHz and with a gain of 1000 × [frequency response 20 ± 5–450 ± 50 Hz (80 dB/decade), System Noise (RTI) < 1.2 μV (RMS) for the specified bandwidth]. Prior to data collection, the accuracy of the electrode placement was tested by isometric contractions of each muscle in order to minimize crosstalk. The electrodes remained affixed during all aspects of the test session.

2.2.3. Procedures

After reading the description of the study, signing the consent form, and completing the pre-participation questionnaire, the dominant leg was determined using the following three tests: ball-kick test, step-up test, and balance-recovery test (Hoffman et al., 1998). The leg that was used most often (i.e. for at least 2 of the 3 tests) to kick the ball, to step onto the step, and to recover balance was in each case identified as the dominant leg for this study. The intactness of the dorsalis pedis pulse and skin surface sensation (using the dermatomes) were also evaluated. For assessment of muscle strength and range-of-motion of the lower extremity, the subjects performed 20 unloaded, full range-of-motion squats; 25 unloaded, full range-of-motion single-leg heel raises;

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and 1 single-leg drop jump from a drop height of 30 cm above the ground. All the test results plus the age, gender, height, and weight of the subject were recorded on a subject screening form.

Following these tests, the subjects were able to practice the jumping procedure up to a maximum of 10 jumps and were then equipped with the electrodes and the electrogoniometer. Prior to any data collection, the subjects performed a 5 min warm-up program using a cycle ergometer. For the pre-test, each subject jumped from a 30 cm high wooden box (placed 3 cm from the force plate), and after ground contact with the dominant leg, the subject rebounded immediately "as high as possible" (drop jump). The drop jumps were performed five times. Then the subjects were asked to lie down in a supine position, and a crushed-ice bag was placed on the dominant limb of the 10 subjects in the experimental group for 20 min. Packs filled with chipped ice are widely used in sports because of the low cost and the high availability. In addition, chipped ice-packs have been shown to have the fastest effect on lowering the temperature of a soft tissue when compared to any other products (Swenson et al., 1996). The ice-pack was applied to the anterior and medial area of the knee joint. In order to prevent skin damage, a dry thin towel was placed between the ice-pack and the skin. For every subject, a bag of the same dimensions was filled with a similar quantity of ice (using the same measuring tool) to be used for joint cooling. In order to attain a similar level of cooling, no compressive bandaging was applied to fix the bag to the knee, such that gravity was the only force holding the ice bag in place. Laterally, the application area was limited by the electrogoniometer, and did not cover the fibular head. Thus, no major peripheral nerves were directly cooled. The subjects in the control group rested without any intervention. Immediately after the 20 min period, the subjects performed the first post-test, using the same protocol as in the pre-test. Then the subjects in both groups were seated and rested for another 20 min without any intervention. A second post-test was performed using the same protocol as in the pre- and the first post-test. The EMG, force plate, and knee angle data were collected and analysed using a custom LabView program (Ver. 8.6, National Instruments™, Austin, TX, USA).

2.2.4. Data reduction

For calculations based on GRF data, only the four channels measuring the vertical direction of the GRF were utilized. The data point that exceeded two standard deviations of the baseline-mean of the summation of these four channels was considered the moment of touch down. The data point that fell below the two standard deviations of the baseline-mean after at least 100 ms of ground contact was considered the push-off moment. A third event marker was determined from the electrogoniometer data as the point of the maximal knee angle between touch down and push-off, which identifies the eccentric and concentric phases. Considering these three event markers, the following segments were defined (Fig. 2): (1) pre-activation phase (100 ms prior to touch down), (2) eccentric (braking) phase (touch down to maximal knee angle), and (3) concentric phase (maximal knee angle to push-off). This segmentation protocol was based on the protocol proposed by Viitasalo et al. (1998). Finally, the length of the eccentric and the concentric phase was calculated.

The mean activity of the obtained raw EMG signal of each muscle was used for a baseline correction. Any power line noise in the recorded EMG signal was removed using a digital notch filter with cut-off frequencies of 59 and 61 Hz. Filtering (Butterworth, second order, zero-lag) was applied in a 10–500 Hz bandwidth and the signal was full-wave rectified. For smoothing, the data were low-pass filtered with a time constant of 20 ms. The signal was normalized to the peak EMG value over all segments of each muscle within the first five pre-test jumps and expressed as a percentage. Finally, the average EMG (aEMG) activity of each of the three segments was calculated.

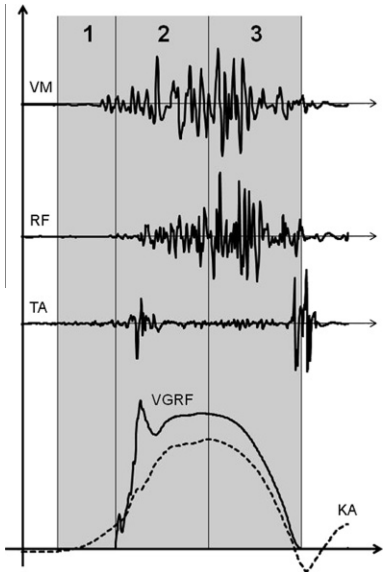

Fig. 2. Definition of the segments [1. pre-activation phase; 2. eccentric (braking) phase; and 3. concentric (push-off) phase] using vertical ground reaction force (VGRF) and knee angle (KA), and the segmentation of three representative EMG signals [vastus medialis (VM), rectus femoris (RF), tibialis anterior (TA)].

2.2.5. Statistical analysis

Statistical calculations were performed using SPSS 16 software package for Windows (SPSS, Inc., Chicago, IL). The independent variables were group (ice/no ice) and time (pre-test/post-test 1/post-test 2). The dependent variables were aEMG (%) of each of the three segments (pre-activation phase/eccentric phase/concentric phase) of the muscles (VM, VL, RF, BF, MG, TA, PL), and segment size (ms) of the eccentric and concentric segments. Each represented the mean of five trials obtained in each group and under each time condition. To determine the effect of group and time on each of the dependent variables, three independent 2 × 2 (group × time) multivariate repeated measures analyses of variance (MANOVAs) were performed (pre-test vs. post-test 1/pre-test vs. post-test 2/post-test 1 vs. post-test 2). In order to prevent a violation of Type I error, a Bonferroni correction was applied and significance was accepted at the $P < 0.0167$ level.

3. Results

3.1. Pre-activation phase

The analysis of the pre-activation phase (Fig. 3) revealed no significant interactions. However, the following trends were recognizable: the pre-activation of the MG and BF muscles tended to decrease immediately after the removal of the ice-application in the experimental group and to increase after the first resting period in the control group. No consistent trends were found between the first- and the second post-test. VM, VL, RF, TA, and PL muscles showed no meaningful differences in this phase.

3.2. Eccentric (braking) phase

For the eccentric (braking) phase, the statistical analysis (Figs. 4 and 6) revealed a significant interaction between time (pre-test vs. post-test 1) and group on segment size ($F_{(1,18)} = 7.637$; $P = 0.013$) with an increase in the experimental and a decrease in the control group. No further statistically significant interactions were found

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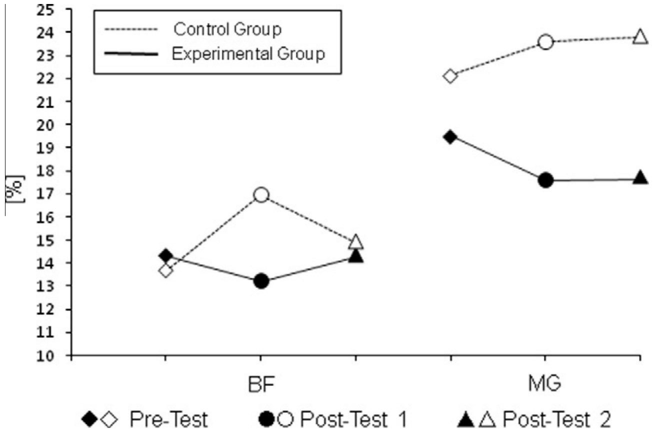

Fig. 3. Average electromyographic activity [aEMG (% of the dynamic maximal value of the five pre-test jumps)] during the pre-activation phase.

for the eccentric phase. However, the following trends were recognizable: BF and PL muscle activity decreased in the experimental group and increased in the control group over the three test times. The MG muscle showed activity decreases in both groups between the pre- and the first post-test but increases in the control group and further decreases in the experimental group between the first and the second post-test. VM, VL and TA muscles indicated activity decreases in the experimental group but no consistent trends for the control group. The RF muscle showed no meaningful differences in this phase.

3.3. Concentric (push-off) phase

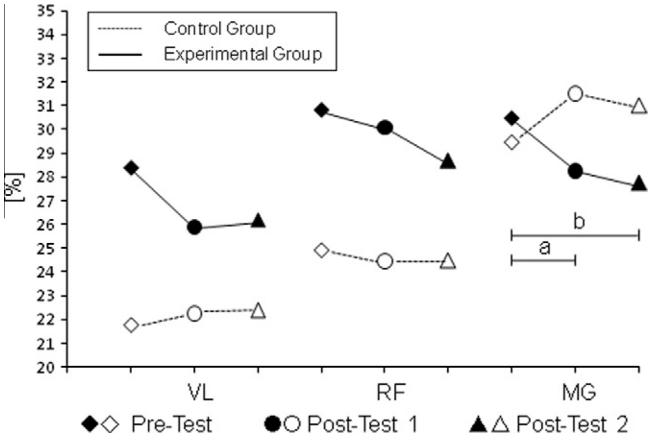

Fig. 5. Average electromyographic activity [aEMG (% of the dynamic maximal value of the five pre-test jumps)] during the concentric (push-off) phase. [a]Significant interaction ($P < 0.0167$) between the pre-, the first post-test, and the two groups. [b]Significant interaction ($P < 0.0167$) between the pre-, the second post-test, and the two groups.

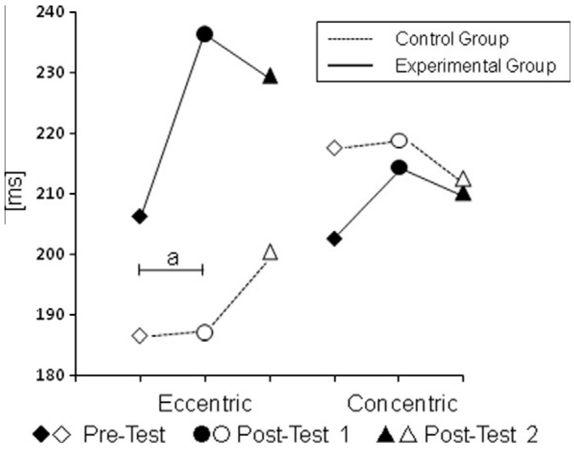

Fig. 6. Segment size [size (ms)] of the five pre-test jumps)] during the concentric (push-off) phase. [a]Significant interaction ($P < 0.0167$) between the pre-, the first post-test, and the two groups.

Figs. 5 and 6 demonstrate the results for the concentric phase. Statistically significant interactions were found for aEMG of the MG muscle between time (pre-test vs. post-test 1) and group ($F_{(1,18)} = 10.407$; $P = 0.005$) and between time (pre-test vs. post-test 2) and group ($F_{(1,18)} = 8.702$; $P = 0.009$) with decreasing activities in the experimental and increasing activities in the control group. No further statistically significant results were found. However, the following trends were recognizable: The VL and RF muscles had decreases in activity from the pre- to the first post-test as well as from the pre- to the second post-test in the experimental group. In the control group, the VL muscle had increases in activity, whereas no consistent trends were observed for the RF muscle. Immediately after the removal of the ice application, the segment size tended to increase in the experimental group and remained unaltered in the control group. The VM, BF, TA and PL muscles showed no meaningful differences in this phase.

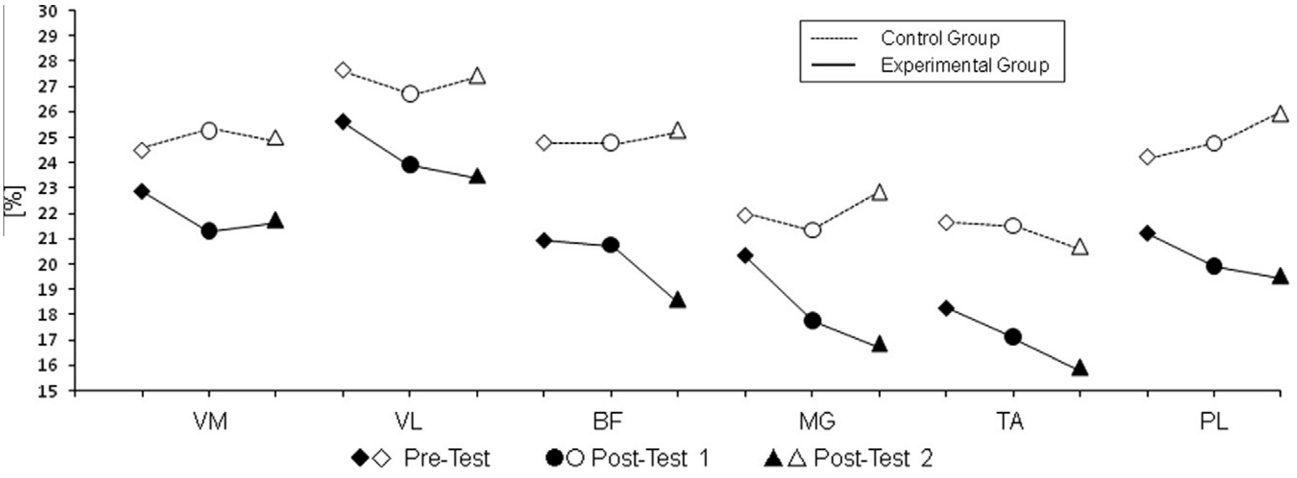

Fig. 4. Average electromyographic activity [aEMG (% of the dynamic maximal value of the five pre-test jumps)] during the eccentric (braking) phase.

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4. Discussion

The hypothesis that the EMG activity of the lower extremity musculature would decrease after a 20-min cold-pack ice-application and that the effects would persist after another 20 min rest has been mainly supported by trends rather than significant differences. The MG muscle revealed the most consistent interaction effects for all of the three phases. For the concentric (push-off) phase, the interaction effects were statistically significant between the pre- and the first post-test as well as the pre- and the second post-test. In addition, muscles that demonstrated decreases in activity in the experimental group included: the BF in the pre-activation and eccentric phases, VL in the eccentric and the concentric phases, VM, TA and PL in the eccentric and RF in the concentric phase. Segment size indicated another significant interaction effect in the eccentric phase between the pre- and the first post-test.

In comparison with prior investigations, the general findings in the current study agreed with those of other researchers that have found decreasing effects of cryotherapy on neuromuscular activity, motor performance, NCV, stretch reflex responses, and proprioception (Algafly and George, 2007; Cross et al., 1996; Fischer et al., 2009; Grey et al., 2001; Hopper et al., 1997; Kinzey et al., 2000; Oksa et al., 1997). Algafly and George (2007) assessed changes in NCV of the tibial nerve, pain threshold, and pain tolerance after a crushed-ice application to the ankle joint for an average duration of 26 min. They found cryotherapy could have an effect on muscular activity by significantly decreasing NCV. However, since no direct measurements were conducted on muscular activity, this statement was only assumed. Several authors studied the effect of 10–20 min of muscle cooling (Fischer et al., 2009; Richendollar et al., 2006) and whole limb cooling (Cross et al., 1996; Kinzey et al., 2000) on maximal high-intensity functional tasks. They all found significant decreases in performance during the following functional tasks: shuttle run; 6-m hop test; single-leg vertical jump (Cross et al., 1996); single-leg vertical jump; agility shuttle run; 40-yard sprint (Richendollar et al., 2006); vertical impulse during a one-legged vertical jump (Kinzey et al., 2000); single-leg vertical jump; co-contraction test; and shuttle run test (Fischer et al., 2009). These results suggest that cryotherapy likely has suppressive effects on the neuromuscular system during high-demanding functional activities. The only study that investigated the effects of cooling on EMG activity during such a functional task was conducted by Oksa et al. (1997). They found a significant decrease in the integrated EMG activity of the triceps surae muscle group during the shortening phase of a maximal rebound jump after 60 min of exposure of the whole body to temperatures of 15 °C and 10 °C. Unfortunately, their cooling protocol was completely different than a local crushed-ice-pack application and thus, the results might not be comparable to the current study. Other researchers studied the effect of 15–20 min of ankle and knee joint cooling on proprioception and found significant decreases (Hopper et al., 1997; Uchio et al., 2003). They concluded that cryotherapy had a suppressive effect on the proprioceptive system. Additional supportive results were presented by Grey et al. (2001) who found that nerve cooling led to a significant increase in the delay of the medium latency reflex response. However, since in the current study no peripheral nerves were directly covered with the ice-pack, decreases in aEMG due to direct cooling of peripheral nerves should be excluded.

In contrast, other studies refuted the decreasing effects of cryotherapy (Atnip and McCrory, 2004; Hopkins and Stencil, 2002; Melnyk et al., 2006; Pietrosimone et al., 2009; Tremblay et al., 2001). Melnyk et al. (2006) evaluated the effect of cryotherapy on the stretch reflex responses of the hamstring muscles (biceps femoris, semitendinosus, and semimembranosus muscles) induced by anterior tibial translation. As an ice-application, they used a cold water-filled tube around the knee for 20 min and found no significant alteration in stretch reflex responses. Hopkins and Stencil (2002) measured the soleus function using the Hoffman reflex and peak plantar flexor torque. They found that the soleus motoneuron pool was facilitated following a 30 min crushed-ice application to the ankle joint. However, both experimental designs did not reflect any functional activity and the results might therefore not be applicable to high demand motor tasks performed by an athletic population. In addition, treatment durations of 30 min and more are rather unusual for athletes (Atnip and McCrory, 2004). For this reason, Atnip and McCrory (2004) studied the effect of 10 min of ankle-cryotherapy on joint kinematics and also found no effects. They concluded that 10 min might not have been enough time to cool down the joint area and to slow the nerve impulses. Tremblay et al. (2001) studied the effect of 20 min of quadriceps muscle cooling on weight discrimination using the quadriceps muscle and found no changes. Pietrosimone et al. (2009) analysed the effect of 20 min of focal knee joint cooling on the electromyographic activity of the rectus femoris and vastus lateralis muscles during a knee extension maximal voluntary isometric contraction (MVIC). They found an increase in vastus lateralis activity. This result indicated that slow movement tasks and isometric muscle contractions were not negatively affected by 20 min of cryotherapy application. Thus, it has been suggested that cryotherapy does not cause a decrease in the amplitude of a muscle contraction but a prolongation of the development of a contraction. This factor and the varying treatment durations could explain some of the controversy among the results of the different studies.

The mechanism that leads to a decrease in muscle activity and consequently in motor performance could be explained as an altered joint proprioception. Several researchers suggested that the activation of the muscles prior to the landing (pre-activation) is pre-programmed (learned through previous experience) and dispatched from higher centers in the nervous system (Avela et al., 1996; Viitasalo et al., 1998). They suggest that pre-activation plays a major role in preparing the muscle for high impact forces and in storing of elastic energy in the cross-bridges and tendons during the eccentric (braking) phase. Avela et al. (1996) presented additional evidence with the assumption that the central program could be modified by proprioceptive, vestibular, and visual inputs. Hence, it has been suggested that a decrease in proprioception, induced by joint cooling, could have resulted in a modification of the central program and thus in a decrease of the pre-landing muscle activity.

Sousa et al. (2007) investigated the fascicle-tendon interaction in the gastrocnemius and soleus muscles during rebound jumps from different drop heights. They found that during the eccentric (braking) phase, the fascicles of the MG muscle shortened in the lower dropping condition, and behaved isometrically in the higher dropping condition, whereas the tendinous tissue in both conditions lengthened. In addition, they described a positive relation between drop height and muscle pre-activation. Ishikawa and Komi (2004) supported these findings with a drop height related fascicle shortening and tendinous tissue lengthening of the VM muscle. They further concluded that the pre-stretch intensity (in their case the drop height) had a crucial influence on the process of storing and subsequently releasing elastic energy. When including these findings in the evaluation of the current study, it can be postulated that cryotherapy causes a decrease in muscle activation prior to ground contact and consequently a reduced pre-stretch activity (aEMG during the braking phase) and storing of elastic energy. This may result in a decreased functional performance due to less elastic energy being released during the push-off phase, which could predispose persons to re-injury following cryotherapy.

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The alteration of the muscle activation prior to ground contact and the following reduction in the storing and releasing of elastic energy could be very influential with regard to risk of re-injury. Although athletes might feel pain-free and ready to perform after a cryotherapy intervention, caution has to be exercised. The reduction in pain could lead to the false expectation of having the same ability to perform as before the intervention without awareness of decreased muscle activity.

The fact that the current study revealed mainly trends rather than significant differences could be due to several limitations. During the ice application, a thin towel was put between the ice-pack and the skin to prevent damage to the skin due to the extreme cold. In sporting competitions however, most athletes or trainers are not concerned with the risk of frostbite, and the ice-pack is often directly applied to the skin. The towel, used in this study, could have decreased the cooling effect of the chipped-ice application.

Further, it was assumed that the joint cooling might have altered the intra-articular nerve conduction and the visco-elastic properties of the capsule, ligaments, and other connective tissue surrounding the knee joint. More detailed knowledge about the effectiveness and the level of cooling could have been achieved by measuring the skin-temperature during and after the ice application.

Another issue in the current study was the fact that all testing was conducted on healthy subjects and might not be applicable to injured persons. Unfortunately, no evidence is available about the effect of cryotherapy on muscle activation in "real" injury situations. Hopkins (2006) examined the effect of cryotherapy after an artificial knee joint effusion on lower chain kinetics and muscle activity. The artificial knee joint effusion served to mimic a "real" injury (inflammatory response) situation. The author however interpreted the exclusion of pain and other inflammatory factors as a decisive limitation of the artificial effusion model.

Ultimately, the small number of subjects appeared to be the most serious limitation of the current study. Future research on the effect of joint cooling on the EMG activity of leg muscles during a plyometric task should include more subjects, while concentrating on a more effective cooling-protocol and monitoring skin temperature. Furthermore, the measurement of kinetics and kinematics could provide valuable information regarding the interpretation of the EMG signal.

In summary, 20 min of knee joint cooling tended to decrease the average EMG activity of the lower extremity musculature during a plyometric exercise. It has been suggested that a diminished proprioception, induced by the cryotherapy application, could have resulted in a modification of the central program and thus in a decrease of the pre-landing and braking phase muscle activity during a plyometric exercise. This may lead to a reduced storage of elastic energy in the tendinous tissue during the eccentric phase and thus to a decrease in performance during the push-off phase. The results lent support to the suggestion that cryotherapy during sporting events may play a role in enhancing risk for re-injury. However, since primarily trends rather than significant differences were found, more data are needed to make definitive conclusions.

References

Algafly AA, George KP. The effect of cryotherapy on nerve conduction velocity, pain threshold and pain tolerance. Brit J Sports Med 2007;41(6):365–9.

Atnip BL, McCrory JL. The effect of cryotherapy on three dimensional ankle kinematics during a sidestep cutting maneuver. J Sports Sci Med 2004;3:83–90.

Avela J, Komi PV, Santos PM. Effects of differently induced stretch loads on neuromuscular control in drop jump exercise. Eur J Appl Physiol 1996;72(5):553–62.

Bleakley C, McDonough S, MacAuley D. The use of ice in the treatment of acute soft-tissue injury: a systematic review of randomized controlled trials. Am J Sports Med 2004;32(1):251–61.

Cross KM, Wilson RW, Perrin DH. Functional performance following an ice immersion to the lower extremity. J Athl Train 1996;31(2):113–6.

Enwemeka CS, Allen C, Avila P, Bina J, Konrade J, Munns S. Soft tissue thermodynamics before, during, and after cold pack therapy. Med Sci Sports Exerc 2002;34(1):45–50.

Fischer J, Van Lunen BL, Branch JD, Pirone JL. Functional performance following an ice bag application to the hamstrings. J Strength Cond Res 2009;23(1):44–50.

Grey MJ, Ladouceur M, Andersen JB, Nielsen JB, Sinkjaer T. Group II muscle afferents probably contribute to the medium latency soleus stretch reflex during walking in humans. J Physiol (Lond) 2001;534(3):925–33.

Hoffman M, Schrader J, Applegate T, Koceja D. Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. J Athl Train 1998;33(4):319–22.

Hopkins JT. Knee joint effusion and cryotherapy alter lower chain kinetics and muscle activity. J Athl Train 2006;41(2):177–84.

Hopkins JT, Stencil R. Ankle cryotherapy facilitates soleus function. J Orthop Sports Phys Ther 2002;32(12):622–7.

Hopper D, Whittington D, Davies J. Does ice immersion influence ankle joint position sense? Physiother Res Int 1997;2(4):223–36.

Ishikawa M, Komi PV. Effects of different dropping intensities on fascicle and tendinous tissue behavior during stretch-shortening cycle exercise. J Appl Physiol 2004;96(3):848–52.

Kinzey SJ, Cordova ML, Gallen KJ, Smith JC, Moore JB. The effects of cryotherapy on ground-reaction forces produced during a functional task. J Sport Rehabil 2000;9(1):3–14.

Melnyk M, Faist M, Claes L, Friemert B. Therapeutic cooling: no effect on hamstring reflexes and knee stability. Med Sci Sports Exerc 2006;38(7):1329–34.

Oksa J, Rintamäki H, Rissanen S. Muscle performance and electromyogram activity of the lower leg muscles with different levels of cold exposure. Eur J Appl Physiol 1997;75(6):484–90.

Perotto A, Delagi EF, Iazzetti J, Morrison D. Anatomical Guide for the Electromyographer: The Limbs and Trunk: Charles C. Thomas; 1994.

Pietrosimone BG, Hart JM, Ingersoll CD. Effects of focal knee joint cooling on spectral properties of rectus femoris and vastus lateralis electromyography. Athl Training Sports Health Care 2009;1(4):154–61.

Richendollar ML, Darby LA, Brown TM. Ice bag application, active warm-up, and 3 measures of maximal functional performance. J Athl Train 2006;41(4):364–70.

Rubley MD, Denegar CR, Buckley WE, Newell KM. Cryotherapy, sensation, and isometric-force variability. J Athl Train 2003;38(2):113–9.

Sousa F, Ishikawa M, Vilas-Boas JP, Komi PV. Intensity- and muscle-specific fascicle behavior during human drop jumps. J Appl Physiol 2007;102(1):382–9.

Swenson C, Sward L, Karlsson J. Cryotherapy in sports medicine. Scand J Med Sci Sports 1996;6(4):193–200.

Tremblay F, Estephan L, Legendre M, Sulpher S. Influence of local cooling on proprioceptive acuity in the quadriceps muscle. J Athl Train 2001;36(2):119–123.

Uchio Y, Ochi M, Fujihara A, Adachi N, Iwasa J, Sakai Y. Cryotherapy influences joint laxity and position sense of the healthy knee joint. Arch Phys Med Rehabil 2003;84(1):131–5.

Viitasalo JT, Salo A, Lahtinen J. Neuromuscular functioning of athletes and non-athletes in the drop jump. Eur J Appl Physiol 1998;78(5):432–40.

Stefan Schmid is a Research Scientist at the Bern University of Applied Sciences (Switzerland). He holds degrees from the School of Physiotherapy Bern (Diploma in Physiotherapy) and from New York University (Masters Degree in Pathokinesiology). His primary research interests include Neuromuscular Aspects of Joint Dysfunctions, Functional Gait Deviations and the Biomechanical Analyses of Movements in Sports and Daily Living.

Marilyn Moffat is a Full Professor of Physical Therapy at New York University, where she directs both the professional doctoral program (DPT) and the post-professional graduate master's degree program in pathokinesiology. She received her Baccalaureate degree from Queens College, her physical therapy certificate and PhD degrees from New York University, and her DPT degree from MGH Institute of Health Professions. She has been in private practice for over 40 years and currently practices in the New York area. Dr. Moffat is currently the President of the World Confederation for Physical Therapy and us a Past-President of the American Physical Therapy Association (APTA).

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Gregory M. Gutierrez is an Assistant Professor in the Department of Physical Therapy at New York University. He received both his Baccalaureate with Highest Honors in Exercise Physiology and Masters of Science in Biomechanics at the University of Florida, followed by his Doctor of Philosophy in Biomechanics and Movement Sciences (BIOMS) at the University of Delaware. He is a biomechanist whose research focuses on neuromuscular control of dynamic joint stability during functional activities, specifically as it pertains to orthopedic injuries.

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