

Effect of walking and resting after three cryotherapy modalities on the recovery of sensory and motor nerve conduction velocity in healthy subjects

Efeito da marcha e do repouso após aplicação de três protocolos de crioterapia na recuperação da velocidade de condução sensorial e motora em sujeitos saudáveis

Esperanza Herrera¹, Maria Cristina Sandoval¹, Diana M. Camargo¹, Tania F. Salvini²

Abstract

Background: Different cryotherapy modalities have distinct effects on sensory and motor nerve conduction parameters. However, it is unclear how these parameters change during the post-cooling period and how the exercise carried out in this period would influence the recovery of nerve conduction velocity (NCV). **Objectives:** To compare the effects of three cryotherapy modalities on post-cooling NCV and to analyze the effect of walking on the recovery of sensory and motor NCV. **Methods:** Thirty six healthy young subjects were randomly allocated into three groups: ice massage (n=12), ice pack (n=12) and cold water immersion (n=12). The modalities were applied to the right leg. The subjects of each modality group were again randomized to perform a post-cooling activity: a) 30min rest, b) walking 15 min followed by 15 min rest. The NCV of sural (sensory) and posterior tibial (motor) nerves was evaluated. Initial (pre-cooling) and final (30 min post-cooling) NCV were compared using a paired *t*-test. The effects of the modalities and the post-cooling activities on NCV were evaluated by an analysis of covariance. The significance level was $\alpha=0.05$. **Results:** There was a significant difference between immersion and ice massage on final sensory NCV ($p=0.009$). Ice pack and ice massage showed similar effects ($p>0.05$). Walking accelerated the recovery of sensory and motor NCV, regardless of the modality previously applied ($p<0.0001$). **Conclusions:** Cold water immersion was the most effective modality for maintaining reduced sensory nerve conduction after cooling. Walking after cooling, with any of the three modalities, enhances the recovery of sensory and motor NCV.

Keywords: cryotherapy; cold therapy; nerve conduction; cooling agents; sural nerve; tibial nerve.

Resumo

Contextualização: Diferentes protocolos de crioterapia têm ação distinta nos parâmetros de condução neural sensorial e motora. No entanto, não se sabe como é o comportamento desses parâmetros no período pós-resfriamento e como o exercício físico realizado nesse período atuaria na recuperação da velocidade de condução nervosa (VCN). **Objetivos:** Comparar o efeito de três protocolos de crioterapia na VCN pós-resfriamento e analisar o efeito da marcha pós-resfriamento na recuperação da VCN sensorial e motora. **Métodos:** Trinta e seis sujeitos jovens e saudáveis foram alocados aleatoriamente em três grupos: criomassagem (n=12), pacote de gelo (n=12); imersão em água gelada (n=12). As modalidades foram aplicadas na perna direita. Os sujeitos de cada grupo foram novamente aleatorizados para realizar uma atividade pós-resfriamento: a) 30 min de repouso; b) 15 min de marcha seguidos de 15 min de repouso. Avaliou-se a VCN nos nervos sural (sensorial) e tibial posterior (motor). Comparações entre VCN inicial e final (30 min pós-resfriamento) foram realizadas com teste *t* de Student pareado. Os efeitos das modalidades e das atividades pós-resfriamento na VCN foram avaliados mediante análise de covariância. O nível de significância foi $\alpha=0,05$. **Resultados:** Houve efeito diferente entre imersão e criomassagem na VCN sensorial final ($p=0,009$). Pacote de gelo e criomassagem apresentaram efeitos similares ($p>0,05$). A marcha acelerou a recuperação da VCN sensorial e motora, independente da modalidade previamente aplicada ($p<0,0001$). **Conclusões:** Imersão em água gelada foi o procedimento mais eficaz para manter diminuída a condução nervosa sensorial após o resfriamento. A marcha pós-crioterapia, com qualquer um dos três protocolos, acelera a recuperação da VCN sensorial e motora.

Palavras-chave: crioterapia; terapia por frio; condução nervosa; agentes de resfriamento; nervo sural; nervo tibial.

Received: 13/05/2010 – Revised: 17/11/2010 – Accepted: 14/02/2011

¹School of Physical Therapy, Health Faculty, Universidad Industrial de Santander (UIS), Bucaramanga, Santander, Colômbia

²Laboratory of Muscle Plasticity, Department of Physical Therapy, Universidade Federal de São Carlos (UFSCar), São Carlos, SP, Brazil

Correspondence to: Esperanza Herrera V, Ciudad Universitaria, Carrera 27 Calle 9, Escuela de Fisioterapia, Universidad Industrial de Santander, Bucaramanga, Santander, Colombia, e-mail: eshevi@uis.edu.co

Introduction ::::

Cryotherapy is a modality often used in clinical and sports environments for treating musculoskeletal injuries both in the acute phase and during rehabilitation. In the acute phase of the injury, the cryotherapy is used mainly to reduce metabolism, cellular hypoxia, pain and edema¹⁻⁶. During the rehabilitation phase, cryotherapy accelerates the process of tissue repair and reduces pain, facilitating the performance of therapeutic exercises and shortening the subject's functional recovery^{1,3,4,6,7}.

A reduction in tissue temperature is the primary effect of cryotherapy, which leads to other physiological changes such as a reduction in metabolic activity and nerve conduction velocity (NCV)^{3,8}. Several studies have analyzed the efficacy of cryotherapy modalities for reducing cutaneous⁸⁻¹⁴, intramuscular^{7,9,14-16} and articular¹⁷ temperature. Previous studies have identified that a crushed ice pack, ice massage and cold water immersion are the most effective modalities for inducing greater and faster cooling⁹⁻¹². Other studies^{7,12,15} have compared the efficacy of different modalities of cryotherapy in the maintenance of tissue cooling after the end of cryotherapy, i.e., during the rewarming period. Rewarming is understood as the recovery of a tissue temperature level similar to that of pre-cooling⁷. After cryotherapy the temperature of the skin recovers quickly¹², while intramuscular temperature remains reduced for some minutes¹⁵. In two of the above-mentioned studies^{12,15}, tissue rewarming was analyzed while the subjects were at rest.

More recently, the effects of exercise after cryotherapy on tissue rewarming have been analyzed. Myrer, Measom and Fellingham⁷ identified that moderate walking, when compared to rest, accelerates the rewarming of triceps surae muscle that had been previously cooled with a crushed ice pack.

A possible explanation for this result is that exercise increases metabolism, blood flow and heat production⁷. As a consequence, post-cryotherapy exercise could reduce the duration of other physiological effects of cooling such as a reduction in NCV.

There is a direct and linear relationship between tissue temperature and NCV¹⁸⁻²⁴. As a consequence, cooling causes a significant reduction in sensory and motor NCV²³⁻²⁵. It is also known that the hypoalgesic effect of cryotherapy, evidenced by the increase in the threshold and tolerance of pain, is associated with a reduction in cooling-induced sensory NCV²⁴. In spite of the importance of NCV for hypoalgesic effects, few studies^{23,25} have compared the efficacy of distinct modalities of cryotherapy for reducing neural conduction. A recent study by our group²⁵, which evaluated the immediate effects of ice pack, ice massage and cold water immersion on the NCV of sural and posterior tibial nerves, showed that the three modalities of cooling significantly reduced the NCV of both nerves. However,

the sensory nervous fibers were most affected by cooling, and cold water immersion was the most effective modality for reducing NCV (mainly motor NCV), probably because it involved a greater area.

The literature on the late effects (post-cooling) of distinct modalities of cryotherapy on sensory and motor NCV is scarce. Consequently, it is unknown if the distinct modalities of cryotherapy are associated with differences in the recovery of basal levels (pre-cooling) of sensory and motor NCV. Furthermore, no study has analyzed the effect of exercise performed immediately after cooling on the recovery of NCV.

In light of the above-mentioned considerations, this study was developed to answer the following questions: a) Are distinct modalities of cryotherapy associated with differences in the recovery of basal levels (pre-cooling) of sensory and motor NCV? b) Does post-cooling exercise (walking) accelerate the recovery of NCV?

This information would be important for recommending different cryotherapy modalities to obtain therapeutic effects associated with reduced NCV, such as hypoalgesia. This type of study would have important clinical applications regarding therapeutic exercise performed after cryotherapy (cryokinetics)⁷ or in situations where the athlete returns to physical activity immediately after being treated with cryotherapy.

The objectives of the present study were to compare the effects of three modalities of cryotherapy (ice massage, ice pack and cold water immersion) on NCV recorded 30 min post-cooling and to analyze the effect of post-cooling physical exercise (walking) on sensory and motor NCV. Considering that cold water immersion is more efficient than other modalities for reducing NCV²⁵, as well as for keeping muscle cool during rewarming¹⁵, the hypothesis of this study was that cold water immersion would also be more effective for maintaining the changes in NCV during the post-cooling period than either ice massage or an ice pack. Moreover, considering that it has already been identified that post-cooling physical exercise accelerates muscular rewarming⁷, another hypothesis of the present study was that post-cooling walking would also accelerate the recovery of motor and sensory NCV.

Methods ::::

An experimental study was conducted with 3 randomly assigned intervention groups (ice massage, ice pack and cold water immersion). For the post-cooling phase, the subjects from each intervention group were randomized again for one of the two post-cooling activity groups: a) 30 min of rest; b) 15 min of walking followed by 15 min of rest (Figure 1). This post-cooling protocol is similar to the one used by Myrer,

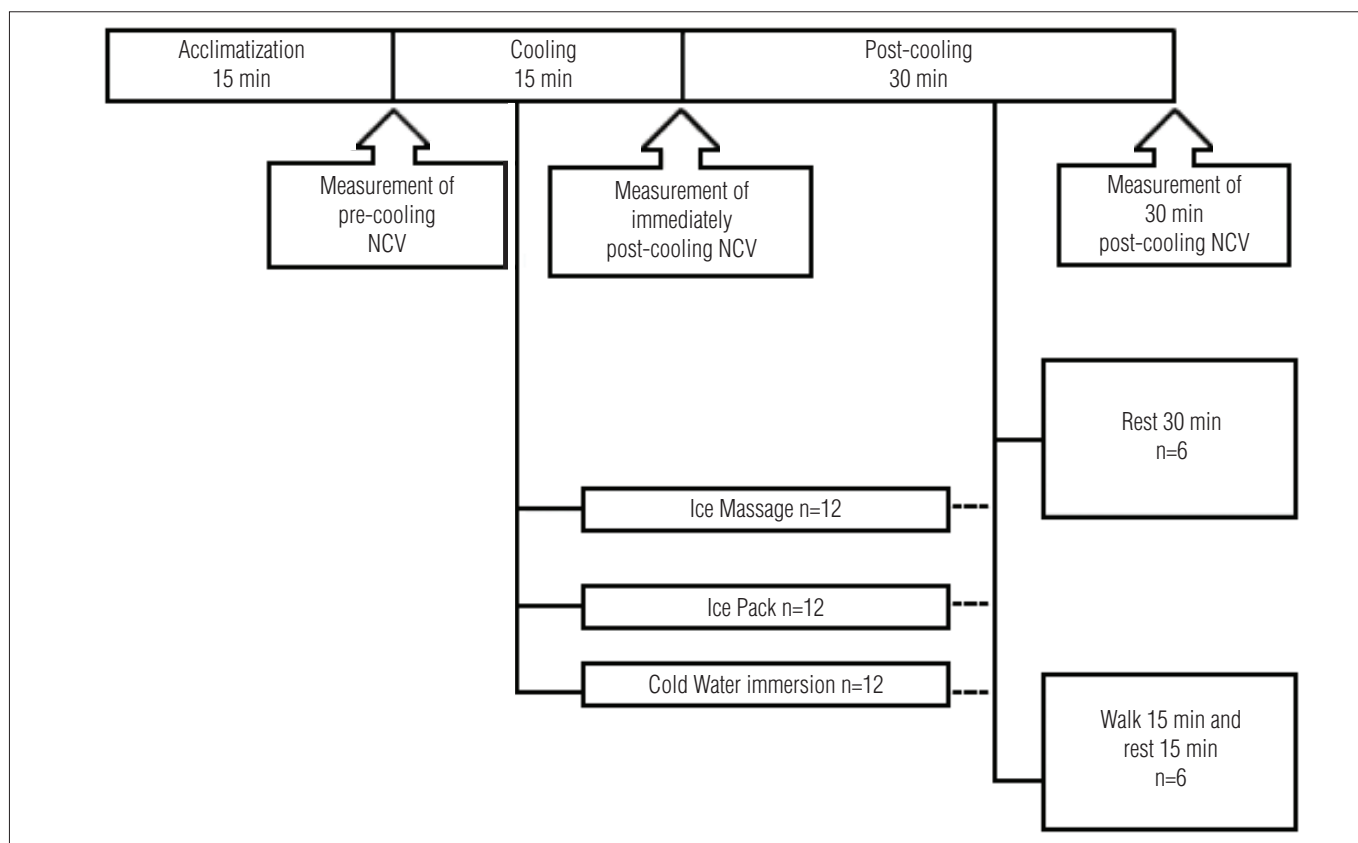


Figure 1. The stages of experimental study, intervention groups and measurement times of motor and sensory nerve conduction velocity (NCV). Each experimental session lasted approximately 60 minutes and consisted of three stages: acclimatization, cooling and post-cooling. The NCV was measured at the three times indicated in the figure. The subjects were randomly assigned to one group of cooling modality: ice massage, ice pack or cold water immersion. At the post-cooling stage, the subjects of each modality group were again randomized to do one of two post-cooling activities: rest 30 min or walk 15 min followed of rest 15 min.

Measom and Fellingham⁷ to analyze the effects of exercise on muscular rewarming after cryotherapy. The independent variables analyzed were: modality of cooling, post-cooling activity and assessment time (pre-cooling and 30 min post-cooling). The dependent variables were motor and sensory NCV (m/s).

Subjects

This research project was approved by the Ethics Committee for Human Research of the Universidad Industrial de Santander, Bucaramanga, Santander, Colombia under protocol n° 18/2006. The subjects signed an informed consent form after having the experimental procedures, risks and benefits of the research explained to them. All the participants filled out a questionnaire on health aiming to determine the presence of some of the following exclusion criteria: BMI < 18.5 or > 24.9, history of alcoholism or smoking, cardiovascular or peripheral vascular disease, diabetes, neurological or musculoskeletal disease, recent trauma or loss of sensitivity, adverse reactions to cold, Raynaud's Phenomenon and pregnancy²⁵.

The calculation of the sample size for each intervention group was determined by the *sampsi* command in *Stata* 9.0 according to the following criteria: $\alpha=0.05$; $(1-\beta)=0.9$; ratio 1:1. The calculation method was repeated measures analysis of covariance (ANCOVA), with one initial and other final measures and a correlation between the measures of $r=0.2$. This method defined a sample of 10-12 participants for each intervention group.

Thirty six healthy subjects (18 women and 18 men) were enrolled in this study. The mean \pm SD age was 20.5 ± 1.9 years, mass 60.2 ± 8.4 kg, height 1.63 ± 0.1 m and BMI 22.4 ± 1.6 kg/m².

Instruments

The nerve conduction studies were carried out with Nicolet Compass Meridian™ (Nicolet Biomedical Company, USA) equipment.

The cooling modalities were chosen because they are considered the most effective for reducing tissue temperature^{9-14,16,25}. For ice massage, an 8×10×5 cm 279 g block of ice was used. The ice pack was an 18×8 cm vacuum-sealed plastic sac containing 279 g of ice. Immersion was carried out in a 20×35×30 cm acrylic

tank containing water and ice with a temperature of approximately 10°C. The tank's temperature was measured throughout the intervention and presented initial and final means of 8.9 ± 1.0 and $7.8\pm 1.2^\circ\text{C}$, respectively. There was no change or addition of ice during any of the cryotherapy modalities.

Procedures

To minimize any circadian effects on body temperature, all experiments were performed between 2:00 pm and 6:00 pm. The subjects were allocated in the cooling and post-cooling activity groups by random computer sequencing²⁶. Considering that the post-cooling measurements had to be taken immediately after the administration of the modalities, the same room was used for all interventions and assessment procedures. Thus, the evaluator knew which intervention had been performed with each subject. Room temperature was maintained at $24\pm 0.08^\circ\text{C}$ without variation during the tests ($p=0.29$). The subjects were instructed to wear comfortable clothes during the experiment. The experimental protocol was developed in three phases: acclimation (15 min), cooling (15 min) and post-cooling (30 min) as shown in Figure 1.

Acclimation phase

During this phase, which lasted 15 min, the subjects rested in a prone position on a standard exam table. Meanwhile, the exact area to be cooled was determined and the electrodes for studying nerve conduction were attached. At the end of this phase, the NCV pre-cooling data were obtained (Figure 1).

Cooling phase

The cooling modalities were applied for 15 min on the right calf of each participant by a physical therapist

trained for this activity. This specific length of application was chosen since it is commonly used in clinical practice and avoids adverse cryotherapy effects²⁷. The length of time allotted for participant adaptation to the cold was not considered before the experimental protocol. All participants completed their cooling protocol with no adverse reactions to the cold.

The procedures for determining the area for cooling treatment are detailed in a previous study²⁵. In brief, for the ice massage and ice pack interventions, the subjects remained lying in a prone position and these modalities were applied to a rectangular area (18x8 cm) on the right calf; compression was not used during the administration of the ice pack. The ice massage was performed with continuous longitudinal displacement. For cold water immersion, the participants remained seated while immersing their leg in a tank to the upper edge of the rectangle that has been drawn for the previous modalities (Figure 2). At the end of the intervention, the leg was quickly dried without friction, and the participant returned to the prone position for post-cooling NCV measurements (Figure 1). These data have already been published recently²⁵ and were not considered in the analysis of the present study.

Post-cooling phase

In this phase, the subjects performed one of the randomly determined activities. Half of the subjects from each modality group ($n=6$) remained resting and lying prone on an exam table for 30 min. The other half ($n=6$) walked for 15 min and then rested for 15 min in the prone position. NCV was then reassessed at 30 min post-cooling (Figure 1). The walking exercise was carried out in a 9.45 m² area at a frequency of 90 steps/min, which was controlled by a metronome, i.e., the subjects stepped at each "click" of the device.



A) Ice massage, B) Ice pack, C) Cold water immersion. The ice massage and ice pack were applied to the same rectangular area (18x8cm) of the calf. Ice massage was performed by continuous longitudinal displacements. The ice pack was placed directly on the skin and without compression. For the cold water immersion, the participants immersed their right leg in a cold water tank as far as the top border of the rectangle used to delimit the cooling area of the other two modalities.

Figure 2. Cryotherapy modalities.

Nerve conduction studies

NCV was registered in the posterior tibial nerve (motor) and in the sural nerve (sensory) at the previously-mentioned times (Figure 1). These nerves were selected because they are located superficially within the treatment area and their recording techniques have been well described^{25,28}. Furthermore, the posterior tibial nerve has a high quantity of motor fibers, and the sural nerve is a pure sensory nerve^{18,28} allowing assessment of the cooling and post-cooling activity effects in both motor and sensory nerves.

All nerve conduction studies were performed by same experienced examiner. The good reliability of these recording techniques repeatedly administered by the same examiner has been previously established^{12,29}. Surface electrodes were used to stimulate and record nerve responses. In order to reduce technical variations between repeated measurements, the stimulation and recording sites were outlined with a waterproof marker during the pre-cooling measurement and the recording electrodes were not removed during the intervention, except for the participants who received cold water immersion. For this procedure, the recording electrodes were removed after the pre-cooling measurement and replaced at the sites previously marked for post-cooling measurements. To calculate the NCV, the peak latency of the negative wave²⁵ was determined.

The sural nerve recordings were obtained with a bandwidth of 20 Hz to 3 kHz, a gain of 20V/division, and a sweep speed of 1 ms/division. A surface recording bar electrode was placed immediately behind the lateral malleolus. The stimulating electrode was placed about 14 cm proximal to the active recording electrode, just lateral to the posterior midline of the calf²⁵. The stimuli were 100 μ s rectangular pulses whose amplitude whose amplitude was adjusted slightly higher than necessary to ensure a maximum response. The nerve signals were obtained by averaging 20 responses.

The tibial motor nerve recordings were obtained with a bandwidth of 2 Hz to 10 kHz, a gain of 2mV/division, and a sweep speed of 2 ms/division. The active disc recording electrode was placed over the abductor hallucis muscle, and the reference disc recording electrode was placed at the base of the hallucis. The ground electrode was positioned on the calf muscle. The distal stimulation site was on the ankle immediately behind the medial malleolus, and the proximal stimulation site was at the popliteal fossa²⁵.

Statistical analysis

Descriptive statistics were used to summarize population characteristics and NCV data, which are presented as mean \pm SD³⁰. Baseline characteristics by intervention group were compared

by analysis of variance (ANOVA) or the χ^2 test, depending of the measurement scale of each variable²⁶. NCV normality was determined by the Shapiro-Wilk test^{26,30}. The initially-recorded NCV and the 30 min post-cooling NCV were then compared for each post-cooling activity group with a paired t-test. The purpose of this comparison was to determine whether there was a complete recovery of NCV 30 min after cooling.

Finally, ANCOVA³¹ was performed to compare the effects of the three modalities and the post-cooling activities on the 30 min post-cooling NCV, adjusting for the NCV measured immediately after cooling. The group that received ice massage and rested after cooling was the reference group for assessing the modality effect. *Stata* 9.0 was used for statistical analysis with a significance level of $\alpha=0.05$

Results

There were no significant differences between participant characteristics in either the three modality groups or the post-cooling activity groups ($p>0.05$, Table 1).

Table 2 presents the results of the initial and final NCV (30 min post-cooling) comparisons. There was a significant difference between the initial and final NCV of the posterior tibial nerve in the groups that rested, regardless of the previously-used modality ($p\leq 0.01$). The cold water immersion group that walked and rested also showed a significant difference ($p=0.019$).

Significant differences were observed between the initial and final NCV (30 min post-cooling) of the sensory nerve in all groups ($p\leq 0.03$), except for the group that walked and then rested after having been treated with an ice pack ($p=0.07$). In general, greater magnitudes of difference were observed in the sensory nerve and in the groups that remained at rest (Table 2).

The ANCOVA showed a significant difference between the cold water immersion group and the group that received ice massage on the sural nerve 30 min post-cooling NCV ($p=0.009$, Table 3). This difference was not observed in the motor signals of the posterior tibial nerve ($p=0.60$, Table 3). There were no observed differences in effect between ice pack and ice massage on 30 min post-cooling NCV ($P>0.05$, Table 3). Regarding the effect of post-cooling activity on the recovery of motor and sensory NCV, it was observed that, compared to 30 min of rest, 15 min of walking followed by 15 min of rest accelerated the recovery of 30 min post-cooling NCV in both nerves ($p<0.0001$, Table 3). This effect was more evident in the sensory nerve, and the coefficient for the sural nerve was higher ($\beta=7.12$) than that determined for the posterior tibial motor nerve ($\beta=3.99$), although the 95% confidence intervals were not statistically different (Table 3).

Table 1. Characteristics of participants by modality and post-cooling activity groups.

Variable	Ice massage				Ice Pack				Cold water immersion			
	All (n=12)	Rest (n=6)	Walk and rest (n=6)	P	All (n=12)	Rest (n=6)	Walk and rest (n=6)	P	All (n=12)	Rest (n=6)	Walk and rest (n=6)	P
Age (y)	19.7±1.3	19.8±1.7	19.7±0.8	0.83	20.7±1.3	20.7±1.8	20.8±1.0	0.84	20.9±2.6	21.5±2.3	20.3±2.9	0.46
Female participants n (%)	5 (41.7)	3 (50.0)	2 (33.3)	0.56	6 (50.0)	2 (33.3)	4 (66.7)	0.25	7 (58.3)	4 (66.7)	3 (50.0)	0.56
Height (m)	1.61±0.1	1.64±0.1	1.59±0.1	0.19	1.64±0.1	1.63±0.1	1.66±0.1	0.59	1.65±0.1	1.66±0.1	1.65±0.1	0.85
Mass (Kg)	58±7.1	59.9±6.4	56.3±7.9	0.40	60.4±8.6	60.7±6.5	60.2±10.9	0.93	62.1±9.7	64.8±10.6	59.6±9.0	0.38
Body mass index (Kg/m ²)	22.2±1.6	22.2±1.6	22.3±1.9	0.91	22.3±1.4	22.9±1.4	21.7±1.2	0.14	22.6±1.7	23.4±1.3	21.9±1.8	0.11

Data are presented as mean±SD, except for the number and percentage of female participants.

Table 2. Results of paired t test comparing pre-cooling NCV with 30 min post-cooling NCV, by post-cooling activity group.

Modality Group	Post-cooling activity Group	NCV of Posterior Tibial nerve (motor)				NCV of Sural nerve (sensorial)			
		Pre-cooling	30min post-cooling	Difference	P	Pre-cooling	30min post-cooling	Difference	P
Ice massage	Rest	50.3±2.2	45.7±2.7	-4.7±2.2	0.003	53.7±2.8	45.7±6.0	-8.0±4.9	0.01
	Walk and rest	49.0±4.3	47.2±3.2	-1.8±2.0	0.08	54.2±3.1	52.2±3.5	-2.0±1.7	0.03
Ice pack	Rest	50.2±4.8	44.7±4.1	-5.5±1.4	0.0002	51.5±5.2	44.5±4.2	-7.0±2.4	0.0008
	Walk and rest	49.0±2.5	49.2±1.5	0.2±2.9	0.89	53.3±3.3	51.5±2.4	-1.8±1.9	0.07
Cold water immersion	Rest	49.7±3.8	40.0±4.2	-9.7±3.6	0.001	54.8±2.4	39.5±2.3	-15.3±1.8	0.0000
	Walk and rest	48.3±3.6	43.8±3.4	-4.5±3.2	0.019	53.3±6.2	48.5±4.9	-4.8±.6	0.02

Table 3. Comparison of the cooling modality and the post-cooling activity effects on the NCV (30min post-cooling), by analysis of covariance (ANCOVA). The 30min post-cooling NCV was adjusted by NCV obtained immediately after cooling. The modality group of comparison was the ice massage and the post-cooling activity group of comparison was the rest.

Variable	Posterior Tibial nerve (motor)			Sural nerve (sensorial)		
	Coefficient (β)	95% Confidence Interval	Probability (P)	Coefficient (β)	95% Confidence Interval	Probability (P)
Ice pack	0.23	-1.72; 2.19	0.81	-1.59	-4.73; 1.55	0.31
Cold water immersion	0.70	-2.00; 3.41	0.60	-4.23	-7.43; -1.15	0.009
Post-cooling activity: walk 15min + rest 15 min	3.99	2.37; 5.60	<0.0001	7.12	4.57; 9.67	<0.0001

Discussion

The results of the present study showed that, compared to only resting, the combination of post-cooling walking and resting accelerates the recovery of NCV in both sensory and motor nerves, regardless of the cooling modality used (Table 3). Moreover, cold water immersion was the most effective modality for maintaining decreased NCV 30 min after cooling, especially in the sensory nerve, which was observed in a previous study²⁵. These results confirm the hypotheses of this study.

In the literature reviewed, no previous studies were found that evaluated the effect of the post-cooling activity on NCV. However, considering the direct and linear relationship identified between tissue temperature and NCV¹⁸⁻²⁴, we can compare our results with the findings of Myrer, Measom and Fellingham⁷, who investigated the effect of exercise (10 min of walking

on a treadmill at 5.63 km/h followed by 20 min of resting) on the recovery of intramuscular temperature after applying an ice pack for 20 min. The main finding of this study was that exercise accelerated muscle rewarming. It is known that exercise increases muscle metabolism, blood flow and the production of heat^{7,32,33}. Therefore, the subjects who exercised after cooling activated the physiological processes that induce a faster recovery of intramuscular temperature and, hence, NCV.

The immediate effect of cooling on NCV had been previously evaluated by our group, showing that sensory nerve fibers are more sensitive to cooling than motor fibers²⁵. The results of this study also show that the magnitude of differences between initial and final NCV (30 min post-cooling) in the sensory nerve was highest when the subjects remained at rest (Table 2). However, there were no significant differences in these variables in either nerve after the application of the three modalities (Table

2), which shows that, especially when subjects only rested, 30 minutes was not a sufficient period of time to fully recover the initial values of sensory and motor NCV.

Several studies^{8,10-12} have compared the effectiveness of these modalities by measuring skin temperature, assuming that changes in skin temperature are closely related to subcutaneous and intramuscular temperature changes. However, it has also been reported that this assumption is not entirely correct since skin temperature does not adequately represent changes in deeper tissues or cooling efficiency; skin temperature decreases faster and at a greater magnitude than muscle temperature^{34,35}.

Our results support this assertion due to the different cooling effect observed in the two nerves situated at different depths. We consider that since the sensory nerve is located more superficially, its changes may be more associated with variations in skin temperature^{9,15}, while the observed changes in the NCV of motor nerve fibers, which are located more deeply, may be more associated with a reduction of intramuscular temperature.

Cold water immersion was significantly more effective in maintaining changes in sensory nerve NCV 30 min after cooling than the other modalities (Table 3). Moreover, the two groups treated with this modality showed differences between initial and final NCV, which shows that there was an incomplete recovery of sensory and motor NCV, regardless of post-treatment activity (Table 2). This result is consistent with the greater effectiveness of cold water immersion for reducing sensory and motor NCV immediately after cooling, which had been previously verified by Herrera et al.²⁵. The greater effectiveness of immersion for reducing and maintaining reductions in NCV for 30 min is probably due to the fact that this modality cools a larger area in comparison with the other two modalities, since almost the entire surface of the leg and foot are immersed.

The technique of cold water immersion presents another difference in relation to ice massage and ice packs in that it is the only modality applied with the lower limb aligned in opposition to the treatment. In the other modalities, the limb was positioned at the same level as the heart. Further studies are necessary to investigate the importance of the extremity's position on the effectiveness of cryotherapy modalities.

We believe that our results provide additional information for both scientific purposes and clinical practice regarding the selection and implementation of cryotherapy modalities. For example, the results show that when it is desired to keep decreasing the sensory and motor NCV by cryotherapy, the

subject should remain at rest after the intervention. Cold water immersion, as used in this study, is the modality most recommended for maintaining the therapeutic effects of sensory nerve conduction changes, such as hypoalgesia. Our results also support the use of cryokinetics, since the three modalities were able to alter sensory conduction at levels recommended to produce hypoalgesia²⁵, which would allow the better performance of therapeutic exercise after cooling. However, such exercise limits the duration of the exercise hypoalgesic effect and requires either the repetition of cryotherapy or the use of another modality after exercise to increase the hypoalgesic effect.

Finally, it is important to point out that a continued decrease in NCV (30 min post-cooling), mainly in resting conditions and without adequate supervision, involves a possible risk of nerve damage in areas where the nerve passes superficially. The literature has shown cases of neuropathy due to the application of cryotherapy along the course of more superficial peripheral nerves^{27,36}.

When analyzing the present study's results, some methodological limitations deserve consideration: the ice massage and ice pack cooling area was smaller than that of cold water immersion; the study population was composed of young and healthy subjects, and it is possible that cooling causes different effects in elderly and medically compromised subjects; the fact that the examiner was aware of the modality used in each group could affect the internal validity of the study; and the absence of another NCV evaluation performed immediately after walking (in the walking/resting group) did not allow verification of whether the subsequent 15 min of rest masked larger effects of walking on NCV recovery.

Conclusion

Walking after cooling accelerated the recovery of sensory and motor nerve conduction. Cold water immersion, as administered, was the most effective modality for maintaining reduced sensory nerve conduction.

Acknowledgments

To the Coordenação de Aperfeiçoamento do Pessoal de Nível Superior (Capes, Brasil) for doctorate funding and to the Universidad Industrial de Santander for financing this research.

References

- 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.
- Oliveira NML, Rainero EP, Salvini TF. Three intermittent sessions of cryotherapy reduce the secondary muscle injury in skeletal muscle of rat. *J Sports Sci Med.* 2006;5:228-34.
- Nadler SF, Weingand K, Kruse RJ. The physiologic basis and clinical applications of cryotherapy and thermotherapy for the pain practitioner. *Pain Physician.* 2004;7(3):395-9.
- Olson JE, Stravino VD. A review of cryotherapy. *Phys Ther.* 1972;52(8):840-53.
- Kowal MA. Review of physiological effects of cryotherapy. *J Orthop Sports Phys Ther.* 1983;5(2):66-73.
- Hubbard TJ, Aronson SL, Denegar CR. Does cryotherapy hasten return to participation? A systematic review. *J Athl Train.* 2004;39(1):88-94.
- Myrer JW, Measom GJ, Fellingham GW. Exercise after cryotherapy greatly enhances intramuscular rewarming. *J Athl Train.* 2000;35(4):412-6.
- Chesterton LS, Foster NE, Ross L. Skin temperature response to cryotherapy. *Arch Phys Med Rehabil.* 2002;83(4):543-9.
- Merrick MA, Jutte LS, Smith ME. Cold modalities with different thermodynamic properties produce different surface and intramuscular temperatures. *J Athl Train.* 2003;38(1):28-33.
- Kanlayanaphotporn R, Janwantanakul P. Comparison of skin surface temperature during the application of various cryotherapy modalities. *Arch Phys Med Rehabil.* 2005;86(7):1411-5.
- Janwantanakul P. Different rate of cooling time and magnitude of cooling temperature during ice bag treatment with and without damp towel wrap. *Phys Ther Sport.* 2004;5(3):156-61.
- Kennet J, Hardaker N, Hobbs S, Selve J. Cooling efficiency of 4 common cryotherapeutic agents. *J Athl Train.* 2007;42(3):343-8.
- Belitsky RB, Odam SJ, Hubley-Kozey C. Evaluation of the effectiveness of wet ice, dry ice, and cryogenic packs in reducing skin temperature. *Phys Ther.* 1987;67(7):1080-4.
- Dykstra JH, Hill HM, Miller MG, Cheatham CC, Michael TJ, Baker RJ. Comparisons of cubed ice, crushed ice, and wetted ice on intramuscular and surface temperature changes. *J Athl Train.* 2009;44(2):136-41.
- Myrer JW, Measom G, Fellingham GW. Temperature changes in the human leg during and after two methods of cryotherapy. *J Athl Train.* 1998;33(1):25-9.
- Zemke JE, Andersen JC, Guion WK, McMillan J, Joyner AB. Intramuscular temperature responses in the human leg to two forms of cryotherapy: ice massage and ice bag. *J Orthop Sports Phys Ther.* 1998;27(4):301-7.
- Warren TA, McCarty EC, Richardson AL, Michener T, Spindler KP. Intra-articular knee temperature: changes ice versus cryotherapy device. *Am J Sports Med.* 2004;32(2):441-5.
- Greathouse DG, Currier DP, Joseph BS, Shippee RL, Matulionis DH. Electrophysiologic responses of human sural nerve to temperature. *Phys Ther.* 1989;69(11):914-22.
- Dioszeghy P, Stalberg E. Changes in motor and sensory nerve conduction parameters with temperature in normal and diseased nerve. *Electroencephalogr Clin Neurophysiol.* 1992;85(4):229-35.
- Halar EM, DeLisa JA, Brozovich FV. Nerve conduction velocity: relationship of skin subcutaneous and intramuscular temperatures. *Arch Phys Med Rehabil.* 1980;61(5):199-203.
- Halar EM, DeLisa JA, Brozovich FV. Peroneal nerve conduction velocity: the importance of temperature correction. *Arch Phys Med Rehabil.* 1981;62(9):439-43.
- Halar EM, DeLisa JA, Soine TL. Nerve conduction studies in upper extremities: skin temperature corrections. *Arch Phys Med Rehabil.* 1983;64(9):412-6.
- McMeeken J, Lewis MM, Cocks S. Effects of cooling with simulated ice on skin temperature and nerve conduction velocity. *Aust J Physiother.* 1984;30:111-4.
- Algaflly AA, George KP. The effect of cryotherapy on nerve conduction velocity, pain threshold and pain tolerance. *Br J Sports Med.* 2007;41(6):365-9.
- Herrera E, Sandoval MC, Camargo DM, Salvini TF. Motor and sensory nerve conduction are affected differently by ice pack, ice massage and cold water immersion. *Phys Ther.* 2010;90(4):581-91.
- Pagano M. Principles of biostatistics. Belmont, Ca: Duxbury Press; 1993.
- Malone TR, Engelhardt DL, Kirkpatrick JS, Bassett FH. Nerve injury in athletes caused by cryotherapy. *J Athl Train.* 1992;27(3):235-7.
- Oh SJ. Clinical electromyography: nerve conduction studies. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2003.
- Herrera E, Camargo DM, Delgado DC, Salvini TF. Reliability of superficial peroneal, sural and medial plantar nerve conduction studies: analysis of statistical methods. *J Clin Neurophysiol.* 2009;26(5):372-9.
- Siegel S, Castellan NJ. Nonparametric statistics for the behavioral sciences. 2nd ed. New York, NY: McGraw-Hill Inc; 1988.
- Vickers AJ, Altman DG. Statistics notes: Analyzing controlled trials with baseline and follow up measurements. *BMJ.* 2001;323(7321):1123-4.
- Bender AL, Kramer EE, Brucker JB, Demchak TJ, Cordova ML, Stone MB. Local ice-bag application and triceps surae muscle temperature during treadmill walking. *J Athl Train.* 2005;40(4):271-5.
- Birch K, MacLaren D, George K. Sport and exercise physiology (Instant Notes). 1st ed. New York: Garland Science/BIOS Scientific Publishers; 2005.
- Jutte LS, Merrick MA, Ingersoll CD, Edwards JE. The relationship between intramuscular temperature, skin temperature, and adipose thickness during cryotherapy and rewarming. *Arch Phys Med Rehabil.* 2001;82(6):845-50.
- Otte JW, Merrick MA, Ingersoll CD, Cordova ML. Subcutaneous adipose tissue thickness alters cooling time during cryotherapy. *Arch Phys Med Rehabil.* 2002;83(11):1501-5.
- Drez D, Faust DC, Evans JP. Cryotherapy and nerve palsy. *Am J Sports Med.* 1981;9(4):256-7.