생활과학석사 학위논문

Alternating cold and heat treatment to alleviate pain of hands and forearms using water perfused gloves during recovery after sports climbing

스포츠 클라이밍 후 손과 전완 부위 통증 경감을
위한 액체 순환장갑을 이용
냉각과 가온의 교대처치

2022 년 7 월

서울대학교 대학원

의류학과

조 가 영

Alternating cold and heat treatment to alleviate pain of hands and forearms using water perfused gloves during recovery after sports climbing

지도 교수 이 주 영

이 논문을 의류학석사 학위논문으로 제출함
2022 년 5 월

서울대학교 대학원
의류학과
조 가 영

조가영의 석사 학위논문을 인준함
2022년 7월

위 원 장 ______________________(인)
부위원장 ______________________(인)
위　　원 ______________________(인)

Alternating cold and heat treatment to alleviate pain of hands and forearms using water perfused gloves during recovery after sports climbing

Joo-Young Lee

Submitting a master's thesis of
Human Ecology
May 2022

Graduate School of
Seoul National University
Dept. of Textile, Merchandising, and Fashion Design

Kayoung Cho

Confirming the master's thesis written by
Kayoung Cho
July 2022

Chair	____________________	(Seal)
Vice Chair	____________________	(Seal)
Examiner	____________________	(Seal)

Abstract

It is well known that sports and rock climbers should grab the artificial hold with strong force of palm and finger joints, thereby muscles and joint pains from forearm to fingers cannot be avoided. As alternating cold and hot water immersion is one of folk remedy for treating muscle and joint soreness, climbing therapists often suggest that this alternating treatment works via the Hunting reaction, and is effective for pain relief than cold water immersion. However, there has been no scientific research on this folk remedy for sport climbers. The purpose of this study was to explore how alternating cold and heat treatments would affect hand and forearm muscles and finger joints soreness in climbers immediately after sport climbing. Nine elite Korean sports climbers participated in this experiment. And, all experiments were conducted at an indoor sport climbing gym. All subjects were treated for a total of 30 min by wearing water perfused gloves according to the following four experimental conditions: Cold, Heat, Cold & Heat, and Control. Using finger grips while climbing increased forearm skin temperature, which indicates a relationship between the usage of finger grips and forearm temperature. The pulley and flexion movement on the middle finger joint was improved the most by the cold treatment, and the recovery rate of forearm activation was also enhanced by the cold treatment. Significantly, the alternating treatment was more effective at lowering the lactate level and skin pain of the fingertips than other conditions. Because the efficacy of each treatment might be affected by its duration, frequency, order, and temperature levels, physiological evidence to support alternating effects should be examined through further studies.

Keywords: thermal treatment, liquid cooling and heating garment, proximal interphalangeal joint recovery, muscle pain, sports climbers

Student Number: 2020-25019

Table of Contents

List of Figures

List of Tables

List of Figures in Appendix

List of Tables in Appendix

List of Abbreviations

BM	Branchialis muscle
EMG	Electromyogram
HR	Heart rate
PIJ	Proximal interphalangeal joint
ROM	Range of Motion
SM	Superficialis muscle
TM	Thenar muscle
T_{sk}	Mean skin temperature

Chapter 1. Introduction

Sport climbing is motivated from rock climbing that grasps artificial sculptures called “hold” on the wall using two hands and foots. There are three categories in sport climbing called lead, bouldering, and speed. Lead competition competes riding a rope and going up using rope and belay devices for safety within a set time. Bouldering is an event that competes to climb from the start hold to the final hold without any lead devices. Speed is literally a game that competes for speed like track on a field. Sports climbing is known as emphasizing specific strength, endurance, gymnastic ability and technique, and the levels of techniques are determined by the size of holds and the distance between a hold and another hold. Also, the angle of the artificial climbing wall decides the climbing grades. In recent years, climbing has become a popular sport among worldwide populations. According to International Federation of Sport Climbing (IFSC), about 25 million people are climbing regularly at indoor and outdoor gyms which have been increasing rapidly impacting from the competition as official Olympic games at Tokyo in 2020 (IFSC, 2020).

As the population of sport climbing increases, aftereffects of climbing have been often reported. In particular, the higher the grades of sport climbing, the smaller the size of the artificial hold; the greater the distance between two holds, the greater the load on the hands and feet. After climbing up, climbers usually suffer from heat pain on palm skins and joint pain on fingers. As long terms, they cannot spread out fingers well due to joint deformans. Sport climbers put a lot of strain on the skin surfaces of the palm, fingers and joints among the fingers because strong force to holds with the palms and fingers is required (Bollen S R, 1990). In addition, high-intensity force on the palms and fingers causes heat sensation as if both hands were burning just after climbing. The longer the exercise experiences, the thicker the palms and the thicker the joints of the fingers when the palms are spread (Schöffl et al., 2003).

In particular, finger injuries are dominantly occurred in national climbing athletes. Shlegel and colleagues (Schlegel C, 2002) found that finger pain was common phenomenon for elite climbers among the Swiss Youth National team (N=29). Schöffl et al. investigated climbing injuries, physical and physiological changes with German youth climbing athletes (15 ~ 40 athletes) for 11 years. They reported that radiographic stress reactions of the hands revealed from the 80% of athletes, and mostly joints of upper limbs were damaged during training and competition seasons (Schöffl et al., 2003). For finger injuries, injuries to the finger flexor pulley system are mostly found in sport climbers (Lutter, 2017). Because the size of holds gets thinner and smaller as climbing grades go up, the hands of climbers get positioned with 'crimp-grip' positions (Schweizer A, 2001). This position affects interphalangeal joints on the fingers and once the A2 and A3 joints of the fingers are flexed and A4 joint is hyperextended. Consequently, the A2, A3 and A4 pulley are considered the most important structures to assess stress and pain levels which can either be strained or ruptured.

Forearm muscles are the most important driving force to determine the power of hand grip strength for climbers. As much as hand grip strength is developed, forearm muscles are inured to uptake the oxygen in blood, and its conductance becomes better than non-climbers (Saul et al., 2019). It means that climbers must own the ability to manage forearm oxygen uptake capacity, which is physiologically called forearm vasodilatory capacity defined by Woollings et al., and it is the significant key to overcome the dead point in climbing routes (Woolings et al., 2015). In order to controlling the oxygen capacity in muscles, there is no doubt that the fast recovery on forearm muscles is inevitable to prepare next climbing sessions. Blood lactate concentrated on the post exercise period cause the isometric contraction of the forearm muscles, consequently the handgrip strength cannot help being lowered. Proper recovery methods are needed to lactate levels lower down in blood vessels of forearm muscles which has a decisive effect to recover climbers' fingers (Booth, 1998).

In order to alleviate muscle and joint soreness of the hands and forearms, most sport athletes use active or passive recovery methods. As one of recovery methods, Nick et al. tried to reduce lactate concentration through light intensity of exercise just after climbing (e.g., 182-m walk for 2-min) (Nick et al., 2006). Watts and colleagues used 25 W recumbent cycling after sport climbing trials. Both studies found that such active recovery methods were helpful to relieve lactic acid levels and heart rates, but insufficient to recover specific body parts damaged by climbing performances (Watts et al., 2000). Baláš et al. firstly designed an experiment how the active recovery influences the finger flexors related to handgrip performance of rock climbers (Baláš et al., 2016) They found that forearm shaking as a type of active recovery methods might assist to recover muscle re-oxygenation of the forearms and could impact finger grip strength. For the passive recovery, resting with only sit position has been normally used to, while

Heyman et al. brought hand immersion methods in cold water for relieving heat pains of finger joints and muscle soreness of the forearms. They set an experimental protocol of 5-min immersion to the 15 ± 1°C of water three times with 2-min intervals, and found that handgrip strength improved after the cold treatment and blood lactate level was lowered after the immersion (Heyman et al., 2009).

Along with the cold-water immersion method, alternating hot–cold water immersion has been used as popular recovery method for the post-exercises There have been numbers of researches made regarding this treatment called as 'contrast bath' or 'contrast water immersion' to relieve muscle stress and restoring metabolic balances. According to Calder's physiological publications, alternating hot-cold therapy is beneficial in terms of increasing peripheral circulation and decreasing lactate concentration. Repeating hot and cold water immersion makes peripheral circulation faster than only the single thermotherapy based on the high rate of metabolic waste. In addition, enhancing blood flow rate cause the lactate level clear down on the fatigued muscle; therefore, it helps to make muscle stress down easier than the single thermotherapy (Calder, 2001). Cochrane reviewed a number of experimental evidence and suggested that alternating hot and cold immersion helps to reduce muscle and joints swellings through vasodilation and vasoconstriction with stimulating blood flow (Cochrane, 2004). It was hypothesized that shunting effects from the vasodilation and vasoconstriction may be one of the mechanisms removing metabolites, repairing the exercised muscle and slowing the metabolic process down. However, there has been still uncertified among sports therapist and exercise physiologists that these alternating methods are physiologically effectual on a certain muscle problem.

Even though the cold-water immersion or the contrast bath has been well-known recovery methods to alleviate muscle and joint pains, few physiological studies for sport climbers, especially for their hands and fingers, were found. In addition, less research is found to be focused on elite athletes in world-wide sport climbing fields. The purpose of this study was to explore how cooling and heating treatments would affect muscle and joint pain of the hands and forearms in climbers immediately after sport climbing. The hypotheses were that 1) the alternating cooling and heating treatment would be more effective in relieving the muscle pain of the hands and forearms than cooling or heating single treatment based on the clearance rate of lactate concentration 2) Alternating cooling and heating treatment would be more effective in relieving finger skin and joint soreness than cooling or heating single treatment on the basis of improving finger range of motions and pain sensations. In particular, we developed a heating and cooling method using water perfused gloves as a more scientific pain relief method in actual sports climbing sites.

Chapter 2. Methods

2.1. Subjects

Nine elite sport climbers (6 males and 3 females) were participated in this study (Mean ± SD: 24.7 ± 4.4 y in age, 166.1 ± 9.2 cm in height, 56.6 ± 7.9 kg in body weight, 20.4 ± 1.8 in body mass index). Eight climbers among nine were right-handed. All subjects have been engaged in Korean National professional climbing team, and were climbing at the Yosemite Decimal System (YDS) 12d-13c with an average climbing career of more than 8-10 years. For the subjects, climbing training hours were on average 5.9 ± 3.3 h per week. Subjects were screened using a basic health exam at Korean National training center, and we accepted subjects who had no doping issues regarding prohibited substances and methods fixed by world Anti-Doping Agency. Subjects were instructed to abstain from alcohol and smoking for at least 24 h before participation. All subjects were informed of the purpose of the study and procedures in advance and presented their written consents. The Institutional Review Board of Seoul National University approved this study (IRB no.2111/001-010).

2.2. Experimental environments and conditions

All trials were conducted at an indoor climbing gym at an air temperature of 24.0 ± 1.5 °C with an air humidity of 50 ± 2%RH. During recovery after climbing, subjects wore water-perfused gloves in the both hands and forearms for 30 min in the following four experimental conditions: Cold, Heat, Alternating Cold & Heat, and Control (no thermal treatment but wearing the gloves) (Fig.A1). The surface temperature inside the water-perfused gloves were maintained at 5°C and 42°C for the cold and heat treatments, respectively. The alternating cold and heat treatment consisted of two bouts of 7.5-min cooling and 7.5-min heating. The water-perfused gloves were made of two layers (an inner layer: 85% nylon + 15% spandex mesh, an outer layer: 92% polyester + 8% spandex) (Fig.A2). Water baths for the cold treatment (C-332, SIBATA, Japan) and for the heat treatment (RW-0525G, JEIO TECH, Korea) were connected to circulate water throughout the gloves (Fig.A3). A pair of water-perfused gloves was covered from both whole hands to the elbows (approximately 11% of the body surface area). Once wearing the water perfused gloves, the additional arm covers (UV sleeves made with 88% polyester 12% polyurethane, Nike Korea, 722 cm^2) were worn to tighten between the glove and the skin (Fig.A4).

2.3 Experimental procedures and measurements

Once arrived at the gym, subjects changed into training shirts and shorts first, and all experimental sensors were attached to the subjects' body. Prior to the climbing, we measured the electromyogram of the forearm, range of motion of the middle finger, pain sensation of proximal interphalangeal joint and fingertip, and lactate level of subjects as baseline values (Preparation) (Fig.A5, A6). After warming up the body with easy climb up movements, subjects performed climbing a set of 40 holds at the climbing spray wall (Fig.1). The grade for the route was 13a for male subjects and 12c for female subjects. All subjects repeated the 40-hold route five times between 10-min intervals. Just after the climbing with the 5-repetitions, electromyogram, range of motion, pain sensation, and lactate level were measured again during the 1st recovery (8min). After the 1st rest period, subjects wore the water-perfused gloves covered from the fingertips to the elbow of both right and left limbs for 30 min (30-min treatment). While the treatment, we asked subjects about the pain sensation of proximal interphalangeal joint and the fingertip. After the 30-min treatment, the electromyogram, range of motion, pain sensation, and lactate level were measured again (the 2nd rest period), which were measured three times in a trial (at preparation, the 1st rest and the 2nd rest period) (Fig.2).

Fig. 1 Endurance training on the spray wall

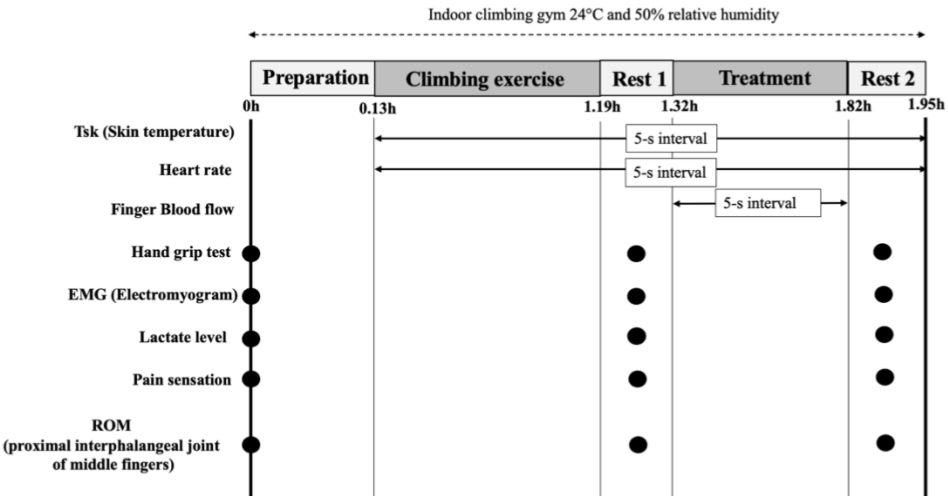


Fig. 2 Experimental protocols and measurement intervals

To measure electromyogram (EMG), resistance of the skin was removed with disinfection alcohol, and then disposable electrodes were attached to the skin where the three muscles were located: branchialis muscle (the upper arm), thenar muscle (the forearm), and superficialis muscle (the upper wrist). (Fig.A7) A ground electrode was attached to the area where the biceps on the opposite side of the measuring electrode pass. In order to quantify the electric potential, muscle activity was recorded while the muscle contraction was done three times through a grip strength test of a hand. EMG during the 5-s muscle contraction with the hand grip tests were analyzed. The hand grip test was repeated three times and the EMG values of the 3-repetitions were averaged. The range of motion on the proximal interphalangeal joint of the middle finger was measured in the following two positions: spreading out and bending the middle finger with maximized using a finger goniometer (Finger goniometer, Preston, USA) (Fig.A8). Pain sensation on the proximal interphalangeal joint and the fingertips were evaluated based on a scale of pain sensation (Score 0: no pain to 10: worst possible pain). Lactate concentration was measured from blood samples of the middle fingertip (the left hand) using a non-invasive tester (Lactate Pro2, Arkray, Japan). Skin temperature (T_{sk}) and heart rate (HR) were continuously recorded from climbing to the 2nd recovery every 5 s. Skin temperatures were measured on seven body regions (the forehead, chest, forearm, thigh, calf, hand, and foot) using a data logger (LT-8A, Gram Corporation, Japan). The measurement sites were left side of the body except the forehead. The skin temperature of the forehead was detected on center position. A weighted mean skin temperature was calculated according to a modified Hardy and DuBois' formula: Mean $T_{sk} = 0.07T_{forehead} + 0.35T_{chest} + 0.14T_{forearm} + 0.05T_{hand} + 0.19T_{thigh} + 0.13T_{calf} + 0.07T_{foot}$ (Hardy and DuBois, 1938). Heart rate (HR) was measured using an HR monitor (RS400, Polar Electro, Finland). Skin blood flow rates were continuously detected for the 30-min treatment only, on both middle fingers with a Laser Doppler skin blood flow device (VMS-LDF2, Moor, England). Also, skin temperature for the fingertip on left hand was measured at the same time with using a data logger (LT-8A, Gram Corporation, Japan). After every trial, we collected subjective opinions on the treatments from all the subjects.

2.4. Data Analysis

For analytical and graphical purposes, skin temperature and heart rate were averaged into 5 min for each exercise and treatment period. Blood flow rate were averaged into whole 30 min in treatment period. All data were presented as mean and standard deviation (mean ± SD) and SPSS 26 was used for statistical analysis with a significance level of $P < 0.05$. Prior to performing further statistical analyses, all data were assessed for normality using a Shapiro-Wilk test. A two-way repeated-measure ANOVA and a Turkey's post-hoc test was undertaken to test for significant differences in parametric values among the four experimental conditions. As a post-hoc test, pair-wise comparisons with FDR correction were used when needed. Non-parametric variables were tested using a Friedman test with Bonferroni correction. During the hand grip strength tests, the EMG signal volume from each muscle was processed by a root mean square (RMS) method and the 3-s values of the 5-s data, except for the first and last 1-s data, was used. The median value was used for analysis to obtain a % value.

Chapter 3. Results

3.1. Lactate concentration

Lactate concentration did not show any differences among the four conditions at the baseline (10.6 mmol in average) and the end of climbing (13.0 mmol in average). However, the lactate concentration at the end of the 30-min treatment was smaller for the alternating cold and heat condition (6.6 ± 3.8 mmol) than the cold (8.8 ± 4.2 mmol), heat (14.3 ± 5.6 mmol) or control conditions (9.0 ± 4.3 mmol) (P<0.001, Fig.3).

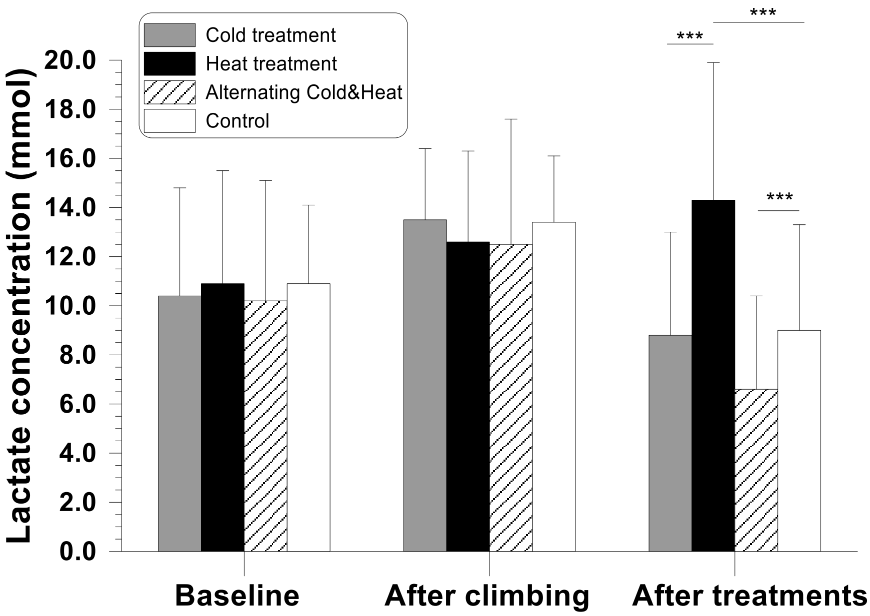


Figure 3. Lactate concentration at the baseline (preparation), the end of climbing exercise (rest 1), and the 30-min treatment after the climbing (rest 2) (N=9; ***P<0.001).

3.2. Hand grip strength and Electromyogram (EMG)

Table 1. Hand grip tests for the four treatment conditions (unit: kg)

Phase	Cold	Heat	Cold & Heat	Control	P-value
Baseline	36.5±8.0	36.9±8.5	35.6±8.0	35.8±7.7	N.S
After climbing	34.3±8.9	34.5±8.8	34.5±7.6	34.0±6.4	N.S
After treatment	35.0±9.4 [a]	33.2±7.7[c]	33.9±7.7[b]	34.0±8.3[b]	<0.001

Table 2. EMG on the brachialis muscle (BM), thenar muscle (TM), and superficialis muscle (SM) during the hand grip tests for the four treatment conditions (unit: %)

Area	Phase	Cold	Heat	Cold & Heat	Control	P-value
BM	Baseline	48.3±8.3	47.6±10.2	48.8±10.3	47.9±9.5	N.S
	After climbing	35.5±10.1	33.7±12.4	36.3±12.6	35.6±11.7	N.S
	After treatment	46.4±10.3[a]	34.2±13.7[d]	41.8±13.5[c]	44.3±12.6[b]	<0.001
TM	Baseline	38.7±11.2	39.5±13.3	37.9±13.5	37.9±11.3	N.S
	After climbing	36.5±10.3	35.8±11.2	35.4±12.1	36.3±11.2	N.S
	After treatment	38.2±11.7[a]	36.3±14.5[b]	38.4±14.2[a]	37.8±13.6[a]	<0.05
SM	Baseline	15.4±4.5	16.2±5.3	15.7±4.2	15.8±4.9	N.S
	After climbing	10.1±4.8	10.5±5.3	11.4±5.5	10.6±7.2	N.S
	After treatment	12.8±3.3	12.3±4.7	12.0±5.4	11.6±3.9	N.S

Note: All data are expressed as mean ± SD;
[a, b, c, d] represent significantly identical groups among the experimental conditions distinguished by a post hoc test.

There were no significant differences in hand grip strength among the four conditions at the baseline and the end of climbing. After the 30-min treatment, however, the hand grip strength was slightly improved for the cold treatment, while the grip strength was weakened after the heat treatment (Table 1). The grip strength was greater after the cold treatment than for other three conditions (P<0.001, Table 1). EMG did not show any differences among the four conditions at the baseline and the end of climbing for the three regions of muscles, whereas there was a significant difference among the four conditions after the 30-min treatment on the brachialis muscle (BM) and thenar muscle (TM) (Table 2, $P<0.05$). On the BM after the 30-min treatment, EMG was the greatest for the cold condition and the smallest for the heat condition ($P<0.05$). On the TM, EMG data was the highest at the cold and heat condition but the lowest at the heat condition ($P<0.05$). EMG in the superficialis muscle (SM) did not show any differences among the four conditions.

3.3. Range of motion (ROM)

Table 3. Range of motion of the middle finger for the four treatment conditions (unit: angle °)

	Phase	Cold	Heat	Cold & Heat	Control	P-value
Extension	Baseline	5.3±6.5	5.4±8.4	5.6±7.9	6.0±8.8	N.S
	After climbing	6.5±7.5	6.7±9.4	6.7±11.1	6.4±9.2	N.S
	After treatment	4.4±6.0[a]	5.9±7.5[c]	5.1±8.7[b]	5.8±8.3[c]	<0.05
Flection	Baseline	78.6±3.9	76.7±6.6	75.2±6.8	78.6±7.7	N.S
	After climbing	84.9±12.0	86.2±11.6	84.4±9.6	82.1±12.5	N.S
	After treatment	80.4±8.5	81.3±7.2	78.8±8.1	80.2±13.5	N.S

Note: All data are expressed as mean ± SD;
[a, b, c] represent significantly identical groups among the experimental conditions distinguished by a post hoc test.

ROM of the middle finger did not show any differences among the four conditions at the baseline and the end of climbing during the extension and flection. However, ROM after the 30-min treatment during the extension showed that the extension angle of the finger joint was the smallest (the most improved) for the cold treatment and the extension angle for the alternating cold and heat treatment was smaller than for the heat treatment or the control (Table 3, P<0.05). During flection, no significant difference among the four conditions even after the 30-min treatments was found (Table 3).

3.4. Pain sensation

Table 4. Pain sensation of the middle finger for the four treatment conditions (unit: score*)

	Phase	Cold	Heat	Cold & Heat	Control	P-value
Fingertip skin	Baseline	1.4±2.0	1.2±2.2	1.3±1.6	1.3±1.2	N.S
	After climbing	3.7±1.7	3.7±2.6	3.6±1.8	3.8±1.8	N.S
	After treatment	3.1±2.0[c]	2.4±2.5[b]	1.0±1.5[a]	2.7±2.1[bc]	<0.001
Proximal interphalangeal joint	Baseline	2.0±1.6	1.9±1.8	2.1±2.0	2.3±1.9	N.S
	After climbing	4.3±2.5	4.1±2.2	4.2±2.1	4.2±2.5	N.S
	After treatment	3.1±2.3	3.8±2.6	3.2±2.6	3.6±2.1	N.S

Note: All data are expressed as mean ± SD;
[a, b, bc, c] represent significantly identical groups among the experimental conditions distinguished by a post hoc test.
*Pain sensation was expressed using the following scale: Score 0: no pain ~ Score 10: worst possible pain.

Pain sensation over the fingertip and joints did not have any differences among the four conditions at the baseline and the end of climbing. After the 30-min treatment, however, subjects felt less painful on the fingertip for the alternating cold and heat treatment and more painful for the cold treatment than other three conditions (Table 4, P<0.001). No significant difference on the joints among the four conditions even after the 30-min treatments were found (Table 4).

3.5. Skin temperature (T_{sk}) and finger skin blood flow

Mean T_{sk} during climbing was on average 32.2 ± 0.3°C. For the 30-min treatment after the climbing, mean T_{sk} were 30.6 ± 0.2, 34.2 ± 0.2, 32.1 ± 0.3, and 33.5 ± 0.1°C for the cold, heat, alternating, and control conditions, respectively ($P<0.05$, Fig. 4). For the 30-min treatment, fingertip temperatures were 26.3 ± 4.8, 36.9 ± 0.5, 33.6 ± 2.4, and 33.7 ± 1.4°C for the four conditions, respectively ($P<0.05$, Fig.5), while forearm temperatures were 29.1 ± 2.4, 36.1 ± 2.0, 31.7 ± 3.2, and 33.4 ± 1.2°C for the cold, heat, alternating, and control conditions, respectively ($P<0.001$, Fig. 6). Hand temperatures were 30.9 ± 1.7, 33.0 ± 1.4, 31.6 ± 1.4, and 32.6 ± 0.9°C for the cold, heat, alternating, and control conditions, respectively ($P<0.05$, Fig. 7).

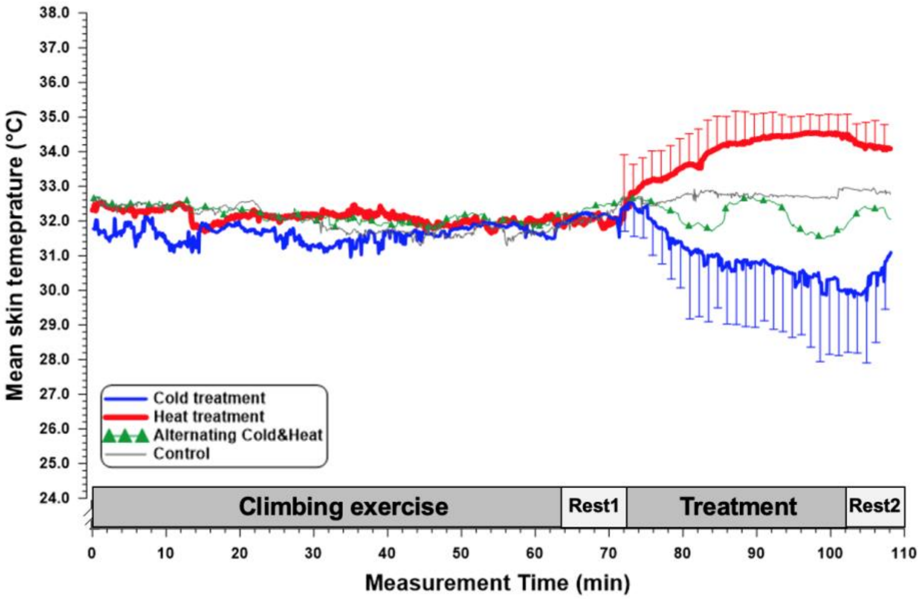


Figure 4. Time courses of mean skin temperatures during climbing and the four treatments in recovery (N=9)

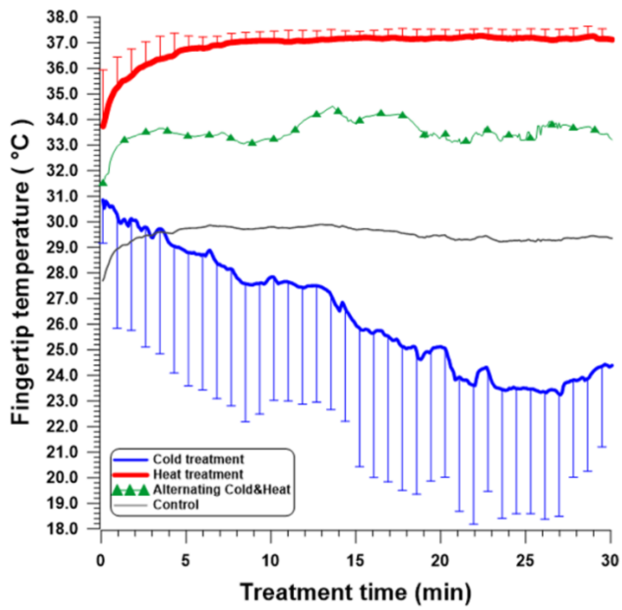


Figure 5. Fingertip temperatures during the treatment time (N=9).

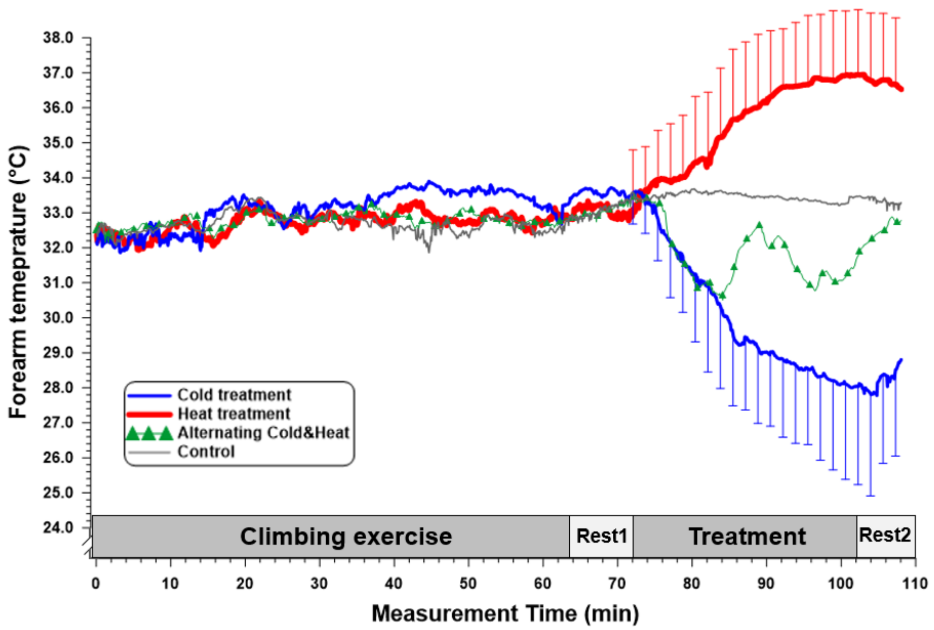


Figure 6. Time courses of forearm temperatures during climbing and the four treatments in recovery (N=9).

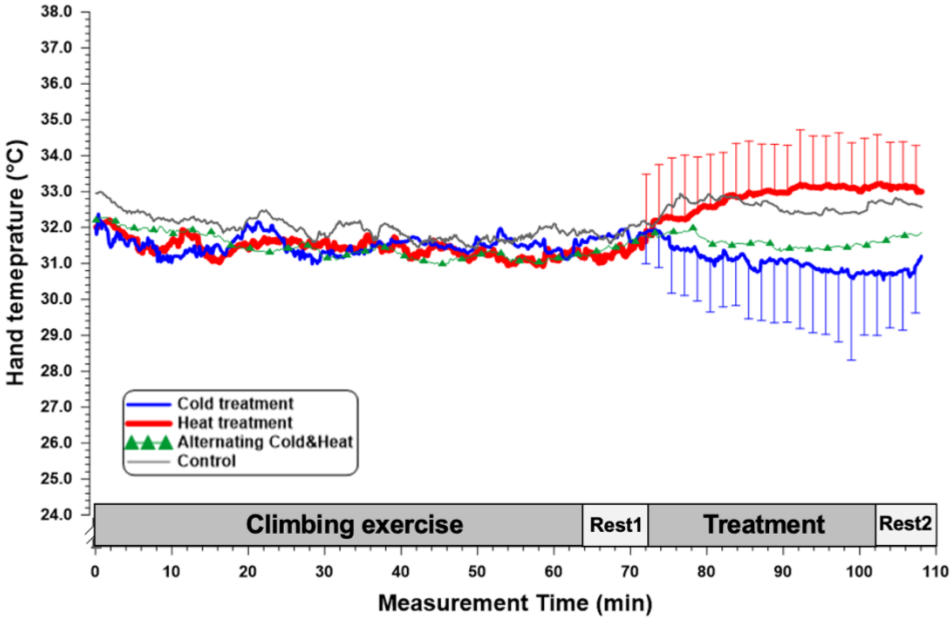


Figure 7. Time courses of hand temperatures during climbing and the four treatments in recovery (N=9).

For the 30-min treatment after the climbing, left finger blood flows were 188 ± 22 (cold), 483 ± 38 (heat), 314 ± 31 (alternating), and 336 ± 30 (control)(P<0.001), while right finger blood flows were 152 ± 24 (cold), 420 ± 40 (heat), 259 ± 24 (alternating), and 312 ± 30 (control) (P<0.001, Fig. 8). Left finger blood flow was higher than the right finger blood flow (P<0.001).

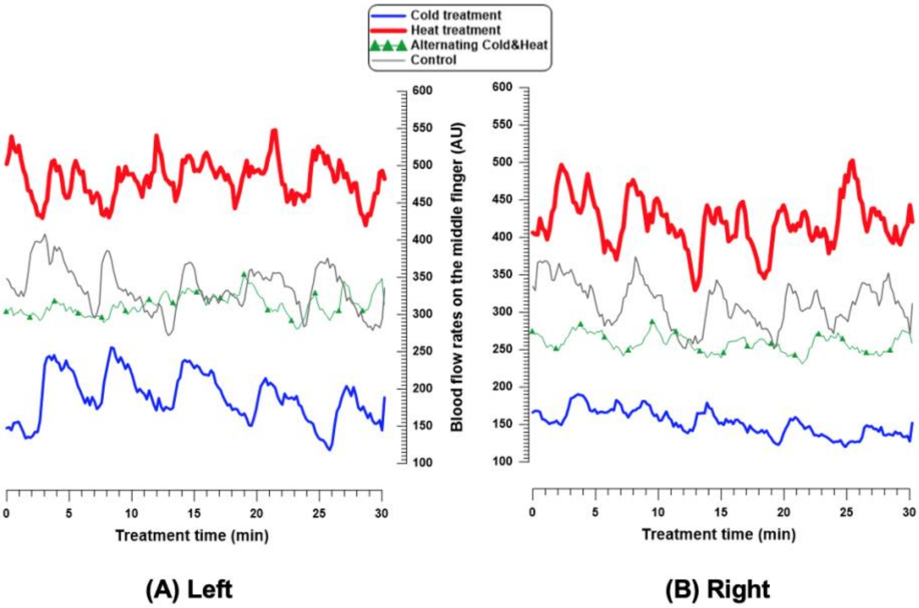


Figure 8. Time courses of skin blood flow in the left finger (A) and right finger (B) during the 30-min treatment for the four treatments after climbing (N=9).

3.6. Heart rate

Table. 5 Heart rate for the four treatment conditions

Heart rate (Unit: bpm)	Phase	Treatment conditions				
		Cold	Hot	Cold & Hot	Control	P-value
	During Exercise	165±3	167±5	167±3	160±7	N.S
	During Treatment	77±5	75±4	74±4	74±5	N.S

Note: All data are expressed as mean ± SD;

Heart rate during climbing was on average 165 ± 5 bpm without any differences among the four conditions. For the 30-min treatment, heart rates were 77 ± 5, 75 ± 4, 74 ± 4, and 74 ± 5 bpm for the cold, heat, alternating, and control conditions, respectively with no significant differences among the four treatments (Table 5).

3.7. Interview after trials

Most subjects felt drowsy during the 30-min heat treatment. A couple of subjects felt more painful over the finger joints after the heat treatment and the heat treatment had no efficacy on the forearms. However, several subjects expressed being recovered after the cold or alternating treatment. Especially in alternating treatment, some subjects answered to feel forearm muscles relaxed when the treatment moved from cold to heat. The training after the day, most subjects said cold treatment were effective on recovering finger joints and forearm muscles. On the other hand, for the training after the next day, the alternating treatment seemed to be effective on recovering finger joints and forearm muscles since subjects felt the best condition of recovery on hands and forearms after the alternating treatment. After the heat treatment, most subjects said it was difficult to exercise on the next day because their forearm muscles got too melted.

Chapter 4. Discussion

The present study explored whether the alternating cold and heat treatment could be an effective method than cold or heat treatments to relive both the muscle pain of hands and forearms and the finger skin and joint soreness immediately after sports climbing. Original findings were that the blood lactate concentration significantly reduced and the pain on fingertips were alleviated during the alternating treatment.

The cold treatment was also effective to the recovery of the forearm muscle strength and extension ability of the finger joint, while no benefit during recovery was found through the heat treatment. To the best of our knowledge, this study was the first attempt to use the wearable devices with a water-perfused gloves, which is able to maintain cooling or heating temperature at constant levels, to recover the muscle and joint pains of sports climbers' hands.

4.1. Lactate concentration and the alternating cold & heat treatment

The most interesting and outstanding finding on this experiment is that the level of lactate concentration was significantly decreased after the alternating treatment. There was previous research regarding the relation between the hand grip strength and lactate concentration of recreational climbers. Based on Watts et al.'s experiments, as the hand grip strength been lowered, blood lactate level was raised in the ratio of 0.76 correlated (Watt, 1996). Also, it took from another research that as the climbing level becomes difficult like the angle of climbing wall gets steep, the lactic concentration increases in accordance with the load on the fingers increases (Giles, 2006). It can be seen that the finger fatigues were accumulated in lactate concentration. In this experiment, the lowest hand grip strength and EMG were measured under the heat conditions, also the lactate concentration was measured to be the highest; it means the finger recovery level after climbing was insignificant at the heat treatment. If so, it is needed to think about the case of why the alternating effect mostly reduced the lactate concentration. As mentioned above, considering that the hand grip strength should be based on the activation of the forearm muscles, the relationship between the physiological mechanism of blood vessels in forearm muscles and excretion of lactic acid should be examined.

Ferguson et al. explained on the previous experiment that, the vasodilation of climber's forearm muscles occurred more easily than non-climbers through continuous endurance training of the forearm muscles (Ferguson, 1997). This means that the climber's forearm muscles are more used to expanding blood vessels than contracting blood vessels to make them suitable for climbing in a short period of time. However, the continued blood vasodilation of the forearm muscles leads to accumulated fatigue in the forearm muscles, and it is difficult to carry out further climbing when climbers exert muscular strength on forearms. In this experiment, when heating is performed, it can be speculated that the muscle fatigue increases due to the further vasodilation under the forearm muscles work, thereby measuring the lactate concentration higher than other treatment conditions. One of pioneering studies about the muscle cooling method conducted that muscle blood flows decrease while the forearm cooling down in water of 10 °C and less caused by the vasoconstriction (Clarke, 1958). In other words, repeating the cooling and heating caused repeating the vasoconstriction and vasodilation, this study revealed the vasoconstriction and vasodilation of blood flows by the alternating treatment was more effective in reducing the lactate level than only the vasoconstriction occurred by the way of cold treatment. In light of previous researches related to muscle and the lactate concentration (Gladden, 2000), it is necessary to measure the lactate uptake and consumption volumes during the vasoconstriction and vasodilation respectively, and check how the ratio can affect the muscle fatigue recovery.

4.2. Pain sensation of hands and the alternating cold & heat treatment

Most subjects answered pains on interphalangeal joints relived at the cold treatment; on the other hand, heat pains on fingertips got better at the alternating treatment. Several subjects also answered that as they felt relieved in the fingertip skin, the pain in the forearm seemed to be also relieved at the alternating treatment. Also at this point, it is necessary to check whether the vasoconstriction and vasodilation of blood vessels at the alternating treatment, such as the relationship between the recovery of the forearm muscles and lactate concentration, affected the pain relief. Physiologically, muscle temperatures are needed to be measured to confirm the mechanism of vasodilation and vasoconstriction of blood vessels at the contrast therapy (Myrer et al.,1997). Lehmann et al. suggested that the muscle temperature should be up to at least 40ºC to recognize the blood vessel mechanisms (Lehmann et al., 1974); however, since it is practically difficult to experiment with a muscle temperature raised by more than 40ºC, the previous experiments about the contrast treatment are difficult to verify physiologically that the vasodilation and vasoconstriction mechanisms were actually occurred at the alternation condition. It can be only assumed that repeating vasodilation and vasoconstriction of blood vessels helped the peripheral circulation and alleviated the heat pains on fingertips.

4.3. Range of motion at finger joints and the cold treatment

According to the results of this study, it was confirmed that the cold treatment was more effective in straightening the finger joints after the recovery period. It can be considered to be meaningful in that this study was the first try since there was no research about measuring the degree of deformation of climbing athletes' fingers according to the Range of motion at proximal interphalangeal joint has been physically improved after the cooling remedy. Generally based on the prominent researches, heating was more effective to stretch out muscles from steady state since heating make the muscle tissue temperature increased, and blood flow rate along with increased (Taylor et al., 1990), consequently the muscle stretch could be improved in blood circulation (Low & Reed, 1994). However, there was few researches about the enhancement of stretches using any thermal treatment after overstraining on joints especially for hands. Therefore, between the cold and heat treatment it could not be concluded which method has been effective to relive overstraining finger joints at this point, but from this experiment, the cooling method can be recommended helping on climber’s finger joints stretched out after exercises.

4.4. Skin temperatures and skin blood flow

As seen on figure 4.-7., there was no significance on the mean skin temperature in exercise period, but forearm, hand, and finger skin temperatures impacted significant on the mean skin temperature in treatment period. Most of all, forearm skin temperature was prominently different among the four experimental conditions than other measurement regions; the forearm skin temperature was increased since forearm muscles were dominantly used for grasping holds and its temperature was also increased as if a certain muscle activation reflects the heat produced depends on circulatory systems (Taylor et al., 2000). Based on previous researches, since the usage of forearm muscles determines how climbers strongly endure hand grips, forearm EMG on muscles was measured to check the level of fatigue on climber's upper limbs (Vigouroux et al., 2006). Ferguson et al. found the importance of isometric forearm contractions of trained rock climbers measuring the vascular conductance responses pre and post exercises. Forearm muscles of trained climbers get being recovered faster than non-climbers since climbers' forearm muscles are stimulated better for the vasodilation (Ferguson, et al., 1997). In this experiment, the degree of forearm muscle usage was well shown through the direct data on skin temperature.

The reason that measuring the finger blood flows were brought from a curiosity which there is any certain periodic characteristics on the alternating treatment compared with other treatment conditions. Being as a result, mean blood flow data during the alternating treatment were presented on averaged between the cold treatment and heat treatment, but no significant result was found on all conditions. The measurement of blood flow itself varies by subject, and noise could not be ignored as well. Most of all, it was assumed that the set climbing route for this experiment was predominant on using left hand since the mean blood flow on the left hand was higher than the right hand.

Chapter 5. Practical applications, Suggestion, and Limitations

5.1. Practical applications: Benefits of water perfused gloves for climbers

Usage of fabricated gloves like those of our study may prove beneficial to athletes as they train or compete. Craig Heller, a professor of biology and Dennis Grahn, senior research scientist at biology lab from Stanford university developed one of water perfused gloves as the purpose of cooling down hands regions (Collins, 2017). The original target to develop this device is for athletes to recover body temperature regulation as cooling down the heat at post exercise stage (Grahn, 2008). However, this device can be only covered the hand regions, and it works only for cooling mode with power suppliers; therefore, it seems to apply for sports climbers to alleviate not only hands also for forearms regions. That’s why the water perfused gloves which are able to covered from forearms to hands version needed to be developed for this experiment.

The biggest advantage for climbers to use water perfused gloves is that their hands doesn’t need to be immersed water directly. Proper dryness of climber’s skin on hand and palm is important since the dryness of skin can determine the level of ability grasping holds during climbing; therefore, if hands immersed to water directly, the surfaces of skin get puckered and limp. It makes difficult to grasp holds immediately during competitions. Secondly, the water perfused gloves we made are quite light weighted (250g per pair) and easily portable devices carrying to climbing spots. In this experiment, the weighted and less portable water bathes were used inevitably because there were no developed portable devices for using thermostatic states. However, since many portable devices which are capable of sufficient power suppliers have been released currently, the water perfused gloves can be used easily at any climbing sites. If portable gloves with thermostatic suppliers are released, it will be very useful for climbers' short-term recovery of hand and forearms between competition sessions. Thirdly, if sufficient power suppliers are able to support thermostatic functions, it is possible to check the muscle contraction and relaxation of tired muscles and joint at constant temperature during treatment, allowing players and coaches to recover through checking the appropriate temperature and treatment time.

5.2. Suggestions

Based on previous habitual recovery methods for climbers, immersion in icing water has been dominantly used internationally. However, considering more effective and practical ways, we suggest that coaches and therapists can apply alternating cooling and heating treatment immediately after climbing to relieve hands and forearms muscle fatigue and pain of elite climbers. Using wearable devices like water perfused gloves which used for this experiment is also suggested in convenience aspect in terms of portability and protection of climbers' upper limb skins. Although proper portable treatment devices have not been introduced yet, for the further development of advanced wearable thermostatic devices, this experiment results can be substantially applied for the recovery treatment and sports rehabilitations.

5.3. Limitations

First of all, the experimental results from alternating cold and heat treatment using water perfused gloves cannot be compared with direct water immersion methods due to limited experimental times. Evaluating compare and contrast data for both treatment methods should be needed to explore which method is more effective physiologically on pains of hands and forearms. Secondly, in the present study, cooling at 5°C and heating at 42°C using a water perfused gloves for 30 min was applied, but the combined effects of various cooling or heating temperatures, treatment durations, body regions, and ambient temperatures should be verified in further studies. Finally, since subjects for this experiment was only limited to elite sports climbers, data would be differently measured depends on climbing careers and skills by non-professionals. Further experiment should have to be needed with various climbing populations in order to using widely these alternating methods as practical remedy. Despite the aforementioned limiting factors, it is believed that the first tried research on exploring the use of water perfused gloves as a new device for sports climber's hands and forearms remedy can add to the previous attempts.

Chapter 6. Conclusions

We explored the effects of alternating cold and heat treatment to relieve pain of hands and forearms for sports climbers using water perfused gloves after sports climbing exercise. The interesting finding of the present study is that the alternating cold and heat treatment was superior to either cold or heat treatment in terms of reducing lactate concentration and pain sensation of the fingertips during recovery immediately after sport climbing. Cold treatment for hand and forearm recovery was also effective to alleviate the grip strength of hands and finger extension, while no benefit of heat treatment during recovery was found. When all the results were combined, it can be thought that only cold treatment method are more effective on the short rest session in the meantime of competitions since grip strength of hands and finger joints being recovered faster in order to grip holds very soon. On the other hands, if a climber needs full time rests without immediate competition in a short time, alternating cold and heat treatment methods would workable to relax muscle stress down around lower limbs area. But most of all, although the identical time of cooling and heating for the alternating cold and heat treatment was applied in the present study, it needs to test the effects of a longer cooling with shorter heating protocol on fatigue, pain sensation and muscle strength of climbers' hands and fingers in further studies. To find the proper treatment time and temperature for the best recovery result will should have to be considered.

References

Bollen SR (1999) Injury to the A2 pulley in rock climbers. Journal of Hand Surgery 15(2):268–70

Booth J, Marino F, Hill C, et al (1999) Energy cost of sport rock climbing in elite performers. British Journal of Sports Medicine 33:14-18

Calder A (2001) The science behind recovery: strategies for athletes. Sports med news: the newsletter of the Australian Sports Medicine Federation (Queensland Branch), Vol. August, pp.2-3

Clarke, R.S.J., R. F Hellon, and A.R. Lind (1958) Vascular reactions of the human forearm to cold. Clin.sci.17:165-179

Cochrane DJ (2004) Alternating hot and cold-water immersion for athlete recovery: a review. Physical Therapy in Sport. 5(1).26–32

Draper N, Bird EL, Coleman I, Hodgson C (2006) Effects of Active Recovery on Lactate Concentration, Heart Rate and RPE in Climbing. J Sports Sci Med. 5(1):97–105

Ferguson RA, Brown MD (1997) Arterial blood pressure and forearm vascular conductance responses to sustained and rhythmic isometric exercise and arterial occlusion in trained rock climbers and untrained sedentary subjects. Eur J Appl Physiol Occup Physiol. 76(2):174-180

Giles LV, Rhodes EC, Taunton JE (2006) The physiology of rock climbing. Sports Med. 36(6):529–45

Gladden, L. B. (2000). Muscle as a consumer of lactate. Medicine and science in sports and exercise, 32(4), 764-771

Grahn DA, Murray JV, Heller HC (2008). Cooling via one hand improves physical performance in heat-sensitive individuals with multiple sclerosis: a preliminary study. BMC Neurol. 5(12) 8:14.

Hardy JD, Du Bois EF, Soderstrom G (1938) The technic of measuring radiation and convection: one figure. J Nutr 15(5):461-475

Heyman E, DE Geus B, Mertens I, Meeusen R (2009) Effects of four recovery methods on repeated maximal rock-climbing performance. Med Sci Sports Exerc. 41(6):1303–1310

International Federation of Sport Climbing. Key Figures: IFSC. https://www. Ifsc-climbing.org/index.php/media-centre/key-figures-2. Accessed April 9, 2020

Jiří Baláš, Michail Michailov, David Giles, Jan Kodejška, Michaela Panáčková, Simon Fryer (2016) Active recovery of the finger flexors enhances intermittent handgrip performance in rock climbers. European Journal of Sport Science. 16(7): 764–72

Laurent Vigouroux, Franck Quaine (2006) Fingertip force and electromyography of finger flexor muscles during a prolonged intermittent exercise in elite climbers and sedentary individuals. Journal of Sports Sciences, Taylor & Francis 24 (2): 181-186

Lehmann, J.F., Warren, C.G., Scham, S.M. (1974) Therapeutic heat and cold. Clinical Orthopaedics 99:207–245

Low, J., & Reed, A. (1994). Electrotherapy explained. Oxford: Butterworth Heinemann Ltd.

Lutter C, El-Sheikh Y, Schöffl I, et al (2017) Sport climbing: medical considerations for this new Olympic discipline. British Journal of Sports Medicine 51:2-3

Myrer, J.W., Measom, G., Durrant, E., Fellingham, G.W. (1997) Cold- and hot-pack contrast therapy: subcutaneous and intramuscular temperature change. Journal of Athletic Training 32(3):238–241

Nathan Collins (2017) https://news.stanford.edu/2017/12/27/cooling-glove-helps-athletes-patients/ (December 27, 2017)

Saul D, Steinmetz G, Lehmann W, Schilling AF (2019) Determinants for success in climbing: A systematic review. J Exerc Sci Fit. 17(3):91-100

Schlegel C, Buechler U, Kriemler S (2002) Finger injuries in young climbers. Schweizerische Zeitschrift für Sportmedizin und Sporttraumatologie 50:7-10

Schweizer A (2001) Biomechanical properties of the crimp grip position in rock climbers. J Biomech. 34:217–23

Taylor, D. C., Dalton, J. D., Jr., Seaber, A. V., & Garrett, W. E., Jr. (1990) Viscoelastic properties of muscle-tendon units. The biomechanical effects of stretching. American Journal of Sports Medicine, 18(3):300-309

Taylor, N.A.S. (2000) Principles and practices of heat adaptation. J. Hum. Environ. Syst. 4:11–22

Volker Schöffl, Thomas Hochholzer, Hans Peter Winkelmann, Wolf Strecker (2003) Injuries in Rock Climbers. Wilderness & Environmental Medicine 14 (2): 94–100

Watts PB, Newbury V, Sulentic J (1996) Acute changes in handgrip strength, endurance and blood lactate with sustained sport rock climbing. J Sports Med Phys Fitness. 36: 255–60

Watts PB, Daggett M, Gallagher P, Wilkins B (2000) Metabolic response during sport rock climbing and the effects of active versus passive recovery. Int J Sports Med. 21:185–90

Woollings KY, McKay CD, Emery CA (2015) Risk factors for injury in sport climbing and bouldering: a systematic review of the literature. British Journal of Sports Medicine 49:1094-1099

Appendix

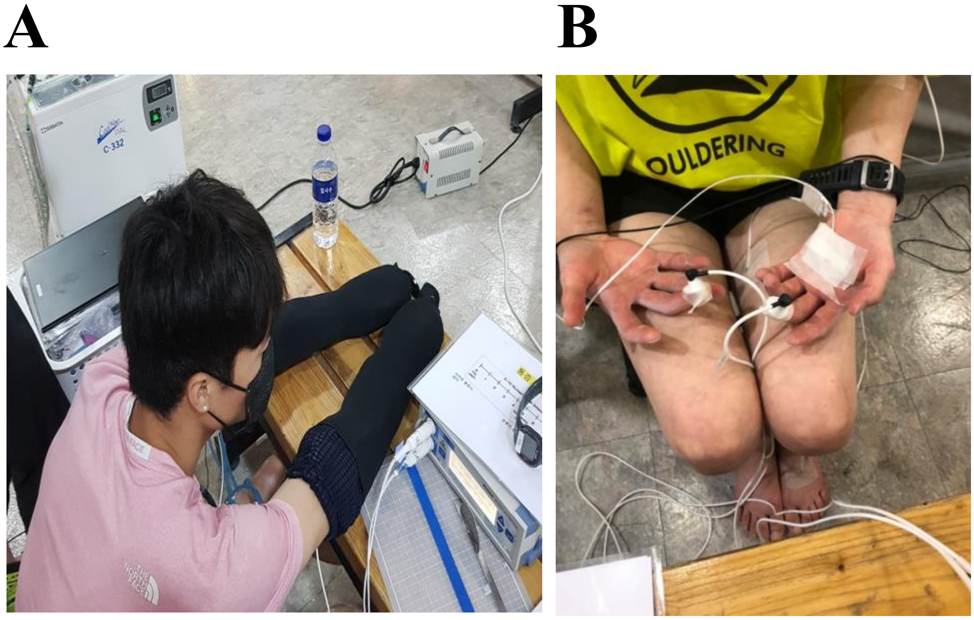


Fig. A1 Treatment period wearing water perfused gloves with cold, heat, and alternating condition(A), and control condition without wearing gloves (B).

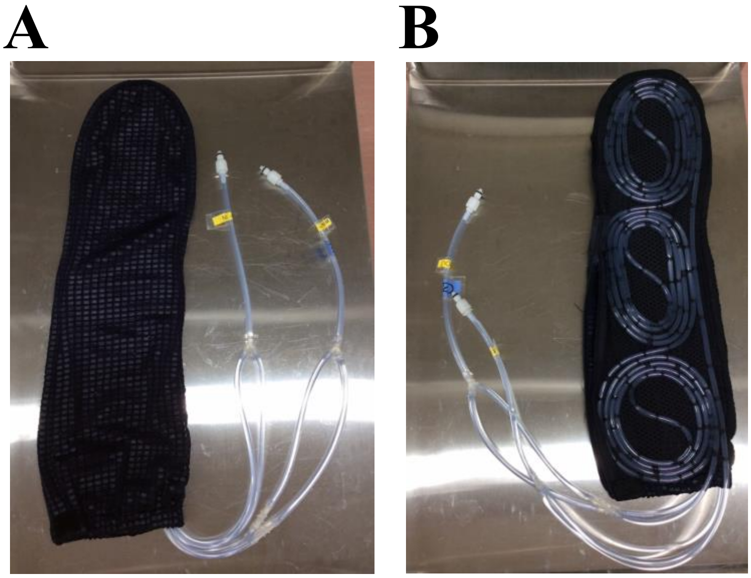


Fig. A2 Outer layer (A) and inner layer (B) of the water perfused glove

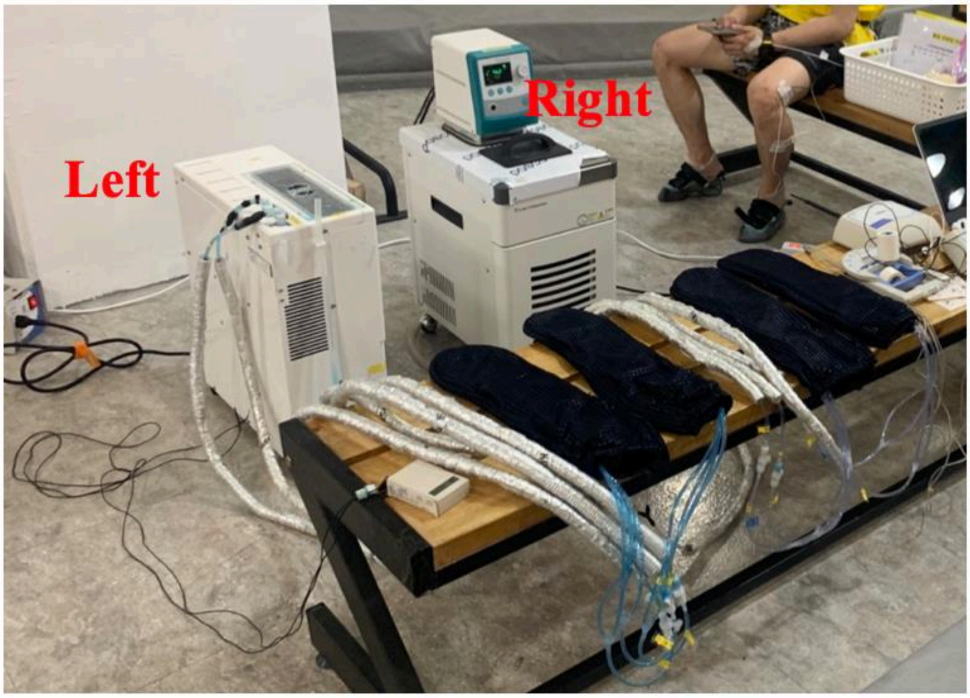


Fig. A3 Water perfused gloves connected to the water baths for cold treatment (Left) and heat treatment (Right).

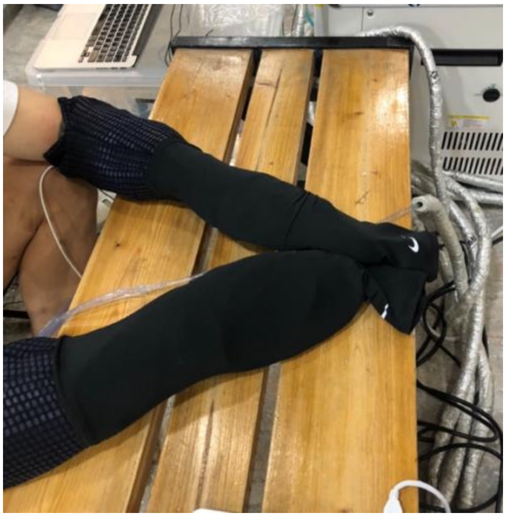
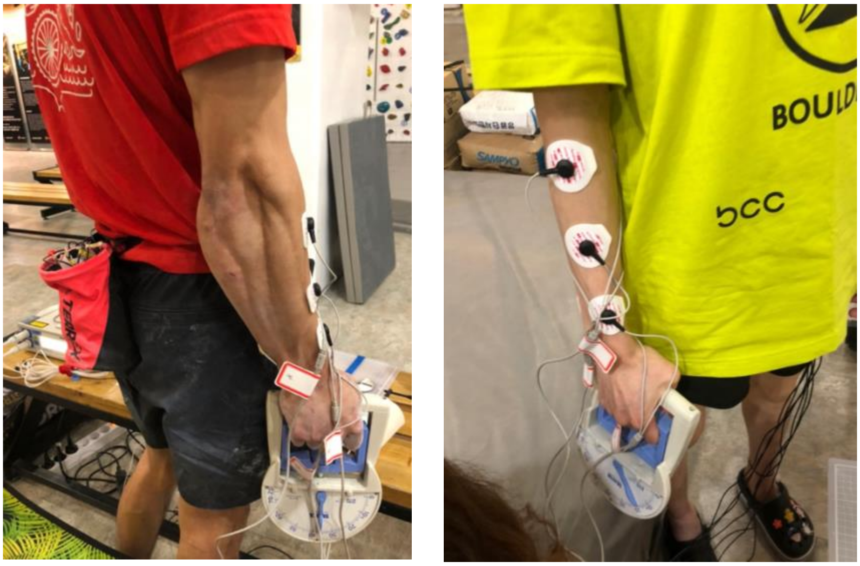


Fig. A4 Arm covers (UV sleeves made with 88% polyester 12% polyurethane, Nike Korea, 722 cm^2) worn on water perfused gloves.

A

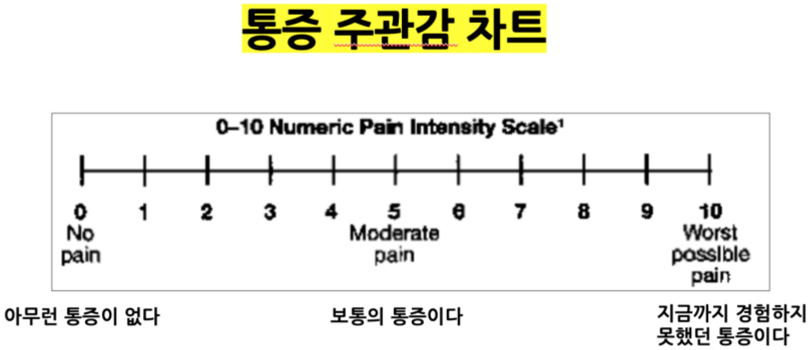


B

Fig. A5 Experimental photos for the EMG of the forearm (A), ROM of the middle finger (B).

A

B



C

Fig. A6 Experimental photos for asking pain sensation of proximal interphalangeal joint and fingertip (A, B), and lactate level of subjects as baseline values (Preparation) (C).

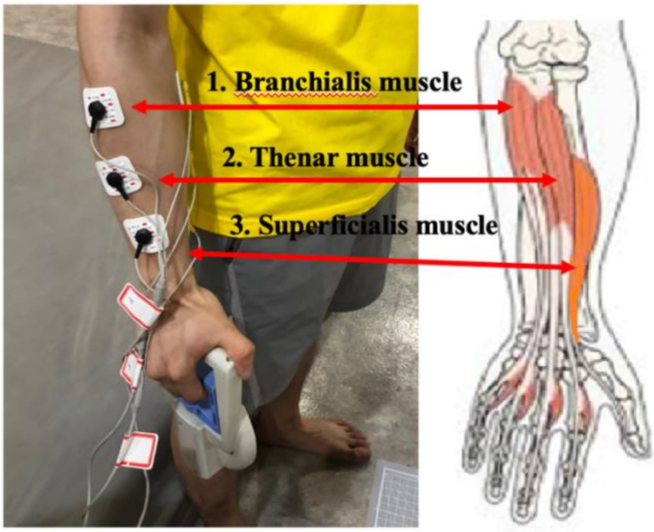


Fig. A7 The locations attaching the electrodes measuring EMG: branchialis muscle (the upper arm), thenar muscle (the forearm), and superficialis muscle (the upper wrist).

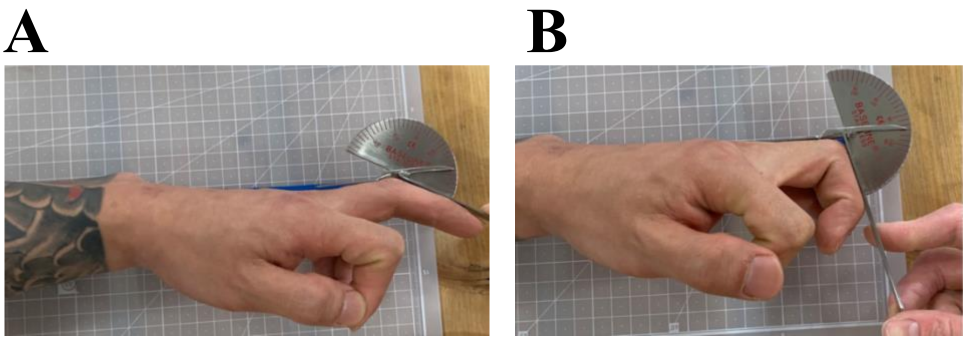


Fig. A8

Measured ROM of the middle finger in the following two positions: spreading out (A) and bending (B) using a finger goniometer.

Table A1. Lactate concentration at the baseline (preparation), the end of climbing exercise (rest 1), and the 30-min treatment after the climbing (rest 2) (unit: mmol)

Phase	Cold	Heat	Cold & Heat	Control	P-value
Baseline	10.4±4.4	10.9±4.6	10.2±4.9	10.9±3.2	N.S
After climbing	13.5±2.9	12.6±3.7	12.5±5.1	13.4±2.7	N.S
After treatment	8.8±4.2[b]	14.3±5.6[c]	6.6±3.8[a]	9.0±4.3[b]	<0.001
Baseline	78.6±3.9	76.7±6.6	75.2±6.8	78.6±7.7	N.S
After climbing	84.9±12.0	86.2±11.6	84.4±9.6	82.1±12.5	N.S
After treatment	80.4±8.5	81.3±7.2	78.8±8.1	80.2±13.5	N.S

Note: All data are expressed as mean ± SD;
[a, b, c] represent significantly identical groups among the experimental conditions distinguished by a post hoc test.

Table A2. Mean skin temperatures during climbing and the four treatments in recovery (unit: ^{o}C)

Phase	Cold	Heat	Cold & Heat	Control	P-value
During Exercise	31.20±1.88	32.30±0.84	32.29±0.73	32.59±1.64	N.S
During Treatment	30.98±1.13	34.10±0.65	32.06±1.10	32.84±0.62	<0.001

Note: All data are expressed as mean ± SD

Table A3. Fingertip temperatures during the treatment time (unit: °C)

Lactate level (Unit: mmol)	Phase	Cold	Heat	Cold & Heat	Control	P-value
	During Treatment	26.33±4.82	36.90±0.47	33.55±2.39	33.73±1.44	<0.05

Note: All data are expressed as mean ± SD

Table A4. Forearm temperatures during climbing and the four treatments in recovery (unit: °C)

	Phase	Cold	Heat	Cold & Heat	Control	P-value
	During Exercise	33.12±1.08	32.84±1.21	32.83±0.97	32.78±1.36	N.S
	During Treatment	29.09±2.35	36.11±1.91	31.66±3.17	33.43±1.24	<0.001

Note: All data are expressed as mean ± SD

Table A5. Hand temperatures during climbing and the four treatments in recovery (unit: °C)

	Phase	Cold	Heat	Cold & Heat	Control	P-value
	During Exercise	31.54±1.36	31.47±1.64	31.46±1.48	32.03±1.04	N.S
	During Treatment	30.94±1.66	32.99±1.37	31.55±1.38	32.61±0.93	<0.05

Note: All data are expressed as mean ± SD

Table A6. Skin blood flow in the left finger and right finger during the 30-min treatment for the four treatments after climbing (unit: AU)

Finger region	Phase	Cold	Heat	Cold & Heat	Control	P-value
Left finger	During Treatment	188.3±21.7^{c}	482.6±38.3^{a}	313.7±30.8^{b}	335.6±30.3^{b}	<0.001
Right finger	During Treatment	152.3±23.5^{d}	420.4±40.2^{a}	258.5±24.2^{c}	311.5±29.6^{b}	<0.001

Note: All data are expressed as mean ± SD

$^{a, b, c, d}$ represent significantly identical groups among the experimental conditions distinguished by a post hoc test.

국문 초록

스포츠 클라이밍은 홀드라 불리우는 인공 조형물이 세팅된 형태와 크기, 그리고 벽에 구성된 홀드의 배열에 따라 오르는 정도의 난이도가 결정되는데, 난이도가 높아질수록 홀드의 크기가 작아지고 홀드사이의 거리가 멀어지면서 손과 발에 걸리는 부하가 커지게 된다. 무엇보다도 손으로 버티는 강한 힘이 필요하기 때문에 클라이밍 직후 손가락피부면의 열통증과 손가락 관절, 그리고 손가락 관절과 연결된 전완근에 많은 무리를 준다. 운동 후 국소부위의 근육 경직과 통증을 완화시키기 위한 단기회복 방법으로 해당 근육부위를 냉각시키는 방법이 일반적인 반면, 운동 후 근육 힘줄의 단기회복을 위한 방법으로 냉각과 가온을 반복 처치하는 연구도 존재하나 이러한 반복처치가 인체 말단 부위 관절 통증 완화에 미치는 영향에 대한 선행 연구는 미흡하다. 본 연구에서는 양손과 아래팔을 감싸는 형태의 액체 순환 장갑을 제작하여 피부 냉각, 가온 또는 냉각 가온의 교대 처치가 클라이밍 직후 손과 전완 부위 통증의 단기 회복에 미치는 영향을 살펴보고자 하였다. 현직 국가대표 남녀 클라이머 9명이 실험에 참여, 실내 클라이밍 센터에서 일정한 루트의 클라이밍을 수행한 후 액체 순환장갑을 이용한 냉각처치(5°C, 30분), 가온처치(42°C, 30분), 냉각과 가온의 교대처치(5°C와 42°C의 교대처치, 각각 7분 30초)를 통해 어느 조건이 통증 완화에 긍정적인 영향을 끼치는 지 살펴보았다. 본 연구는 냉각과 가온의 교대 처치가 클라이밍 직후 젖산 농도와 손끝 피부면 통증을 완화시키는데 효과가 있다는 유의한 결과를 가져왔다. 냉각처치만을 시행했을 경우 손가락 악력과 손가락 펌 관절의 회복에 도움을 주었지만, 가온처치만을 시행했을 시에는 운동 직후 어떠한 회복에 있어서도 긍정적인 효과를 가져오지 못했다. 본 실험에서는 교대 처치 시 냉각과 가온의 시간을 각 15분이란 시간으로 한정하여 진행했으나, 추가 실험을 통해 손 부위와 전완 근육의 피로도와 통증 완화에 더욱 적합한 냉각과 가온의 처치 시간을 확인할 필요가 있다.

주요어: 냉각과 가온처치, 액체 순환 장갑, 손가락 관절 회복, 근육 통증, 스포츠 클라이밍