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Research article

Continuous Knee Cooling Affects Functional Hop Performance – A Randomized Controlled Trial

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Abstract
Cryotherapy is widely used in sports and rehabilitation to aid recovery and injury management. The purpose was to examine if a low temperature computer controlled continuous knee cooling protocol (10°C) for one hour and a moderate continuous knee cooling protocol (18°C) for one hour affected neuromuscular activity and functional performance tests. We used a randomized controlled study design. Twenty healthy male subjects (age = 24 ± 3 years) were included and randomized into 2 groups (10°C and 18°C). On day one, participants performed a maximal voluntary contraction of the quadriceps (MVC), single leg hop for distance (SLHD), and crossover hop for time (COHT) with both legs before and after cooling of their right leg. At day two, the same tests were performed with both legs before and after cooling of the left leg. Participants exposed to the 10°C-protocol showed a significant decrease in SLHD and COHT performance. For the 18°C-group, no significant changes in SLHD and COHT outcomes were noted. In both groups, EMG frequency during MVC decreased, but no significant increases were found in EMG amplitude. Continuous knee cooling at 18°C for one hour does not affect functional hop performance, though adaptations at the muscle level (EMG frequency decrease) can be observed. Applying a similar cooling protocol with 10°C results in a significant decrease in functional hop performance and EMG frequency. EMG amplitude remained unaffected. This infers that changes at muscle level due to local temperature manipulations may not always be detrimental to functional performance.

Key words: Cryotherapy, neuromuscular activity, electromyography, functional performance, hop test.

Introduction

Cryotherapy or, the application of non-invasive cold modalities, results in a decrease in tissue temperature and is widely used in sports and rehabilitation to aid recovery and injury management (Costello et al., 2012). Cooling decreases blood flow (Thorsson et al., 1985), nerve conduction velocity (Algafly and George, 2007; Herrera et al., 2010), and muscle spindle activity (Oksa et al., 2000). When cooling is applied prior to physical performance, these physiological changes and interactions between those various systems may eventually lead to a deterioration in physical performance (Bleakley et al., 2012; Drinkwater, 2008).

Knicker and colleagues (2011) described that physical performance can be assessed at muscle, exercise or competition level. Muscle performance tests aim to determine the complete functioning of a single muscle through repeated contraction (e.g. maximal voluntary contraction) and are often measured by electromyography (EMG). In contrast, functional performance tests cover whole-body exercise tests that are easy to use in laboratory or field settings (i.e. repeated sprints, hop and jump tests, agility tests) and can be assessed in either a quantitative or qualitative way (Knicker et al., 2011).

In terms of muscle performance tests, a linear relationship between increasing force and, EMG amplitude and total power of the EMG power spectrum can be observed (Drinkwater, 2008). The application of different cooling modalities to muscle tissue induces changes to the neuromuscular activation pattern and could eventually lead to an unfavorable effect on muscular performance (Vieira et al., 2013). Drinkwater (2008) reported an increase of the EMG signal during various contraction types as long as the intra-muscular temperature remains above 20°C. These findings can also be translated to changes in mechanical muscle properties, namely an increase in stiffness and tension, and a decrease in elasticity of the muscle (Mustalampi et al., 2012). However, when intra-muscular temperature decreases below the 20°C threshold, a substantial reduced EMG amplitude can be observed, which could lead to a decrease in muscle strength (Drinkwater, 2008).

Bleakley et al. (2012) performed a systematic review on the effect of local pre-cooling on functional performance, and found that muscle strength, vertical jump, sprint and agility performance immediately deteriorated after cooling, but also concluded that there is still a lot of conflicting evidence on the effect of cryotherapy on functional performance outcomes. Moreover, most studies examining functional performance deficits used aggressive or short-term cooling methods (e.g. cold packs, cold water immersion, ice bags) and were not able to standardize the administered treatment temperature accurately (Bergh and Ekblom, 1979; Cross et al., 1996; Evans et al., 1995; Fischer et al., 2009; Patterson et al., 2008; Richendollar et al., 2006).

In the last decade computer controlled cooling devices started emerging in both orthopedics, rehabilitation and sports. In contrast to previous, primitive cooling modalities (e.g. ice bags, cool packs), computer controlled cooling devices have the ability to cool and control the administered temperature very precisely and distribute it equally across the joint or muscles. Recently, Hohenauer et al. (2017) used a continuous computer controlled cooling application to examine the effect on maximal and submax-

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imal voluntary contractions related to peripheral and central fatigue. However, they found no changes in isometric maximal voluntary contraction (MVC) of the quadriceps after a 20 minute cooling period at a temperature of 8°C (Hohenauer et al., 2017). Nevertheless, these cooling devices are more time dependent than conventional cooling methods and therefore need more time to achieve significant temperature decreases in subcutaneous tissues (e.g. muscle). This could clarify why no differences in MVC were found after cooling for only 20 minutes. However, the potential perturbations that cooling can cause at muscle level and its relation to fatigue could give us new insights regarding how muscle and functional performance interact. To our knowledge, the use of a computer controlled continuous cooling application has never been used to study its effects on neuromuscular activity and functional performance.

Therefore, the purpose of this study was to examine if a low temperature computer controlled continuous knee cooling protocol (10°C) for one hour and a moderate temperature computer controlled continuous knee cooling protocol (18°C) for one hour affected neuromuscular activity of the musculus quadriceps vastus medialis and functional performance tests..

Methods

Trial design

We used a randomized controlled study design. Independent variables were the study population, the cooling intervention and the time between pre- and post-tests. The primary dependent variables were distance for the Single Leg Hop for Distance Test (SLHD), time for the Six Meter Single Leg Crossover Hop Test for Time (COHT), and EMG activity during MVC of the quadriceps vastus medialis. A secondary dependent variable was skin temperature of the knee.

Participants

Twenty healthy male subjects (age = 24 ± 3 years, length = 1.82 ± 0.07 m, weight = 76.05 ± 9.53 kg) with no history of injury or surgery to the lower extremity were included in this semi-crossover study and randomized in either Group 1 (10°C-protocol versus no cooling) or Group 2 (18°C-protocol versus no cooling) by using a random sequence generator and were blinded for the intervention temperature. Participants always received the same cooling protocol temperature, once they were allocated to a designated group. The cooled leg always served as the intervention condition and the non-cooled leg as the time-matched control condition within the designated group in order to be sure that we were measuring the effect of cooling and not the effect of sitting down for one hour (see Figure 1). Demographic characteristics of the participants are shown in Table 1. Participants were excluded when they sustained an injury during the trial period, had a BMI ≥ 30, or stated contraindications to cryotherapy (e.g. cold allergy). Subjects were physically active, practicing sports minimal two times a week and had a normal BMI (BMI = 18.5 - 25).

The study was approved by the institutional medical ethics committee of the university hospital UZ Brussels and Vrije Universiteit Brussel (Belgium) (B.U.N. 143201629149). All participants were provided written and oral information about the experimental procedures and possible risks, and signed the written informed consent before the experiment. All procedures were conducted according to the Declaration of Helsinki.

Table 1. Participant demographics (mean ± SD).

Intervention Groups	Group 1 (10 °C) N = 10	Group 2 (18 °C) N = 10
Age (yrs)	24.4 ± 3.73	23.3 ± 3.12
Heigth (m)	1.82 ± 0.04	1.81 ± 0.09
Weight (kg)	77.8 ± 5.79	74.3 ± 12.07
Leg dominance (l/r)	5/5	5/5

Procedures

Participants came to the laboratory twice: on day one, subject characteristics as age, length, and weight were registered. Next, participants performed a MVC of the quadriceps vastus medialis, SLHD, and COHT with both legs before and after the cooling of their right leg. At day two, the same tests were performed with both legs before and after cooling of the left leg. All performance tests were always executed with the cooled leg first, to maximize the effect of cooling, then with the non-cooled leg. On both test days, subjects were scheduled at the same time of day. Mean ambient temperature during these trials was 26.3 ± 2.1°C.

Cryotherapy application

A computer controlled cooling device (CTS100, Waegener NV, Belgium) administered continuous cooling through a knee cuff during 1 hour. The knee cuff covered the whole knee joint, musculus vastus medialis and proximal part of the calf muscles. This device enables the user to select different cooling parameters (e.g. temperature and time), while the internal computer system regulates and controls the selected temperature and duration, and provides a continuous flow of cold liquid through the cuff. The right leg was cooled on the first visit and the left leg on the second visit. Either a cooling temperature of 10 °C (group 1) or 18 °C (group 2) was selected, depending on which group participants were assigned to at the beginning of the trial. During the cooling intervention, participants were seated on a physiotherapy table with both legs extended The cooling interventions were separated by at least 24 h.

Monitoring skin temperature

Four skin thermistors (Gram corporation LT-8A, Saitama, Japan) were placed between the knee-cuff and skin of the knee to monitor the effect cryotherapy on skin temperature. These thermistors were placed on the quadriceps tendon, patellar tendon (tibial tuberosity), distally on the thigh between the m. semitendinosus and m. biceps femoris, and between the proximal heads of the m. gastrocnemius. Baseline knee skin temperature was determined prior to cooling. During the cryotherapy intervention, skin temperature was noted every ten minutes. Afterwards, the mean values of the thermistors were calculated for every time point.

Functional Performance Tests

Single Leg Hop for Distance Test (SLHD)

The participant was instructed to stand on one leg, then

jump as far as possible, and to land on the same leg. The starting position was indicated by a designated horizontal line. The test was considered successful when the participant was able to balance for at least three seconds after the landing. The distance was measured from the horizontally designated line up to the heel of the participant and was immediately noted after a valid jump. Furthermore, SLHD is a reliable tool for lower extremity performance testing and contains small measurement errors (Booher et al., 1993).

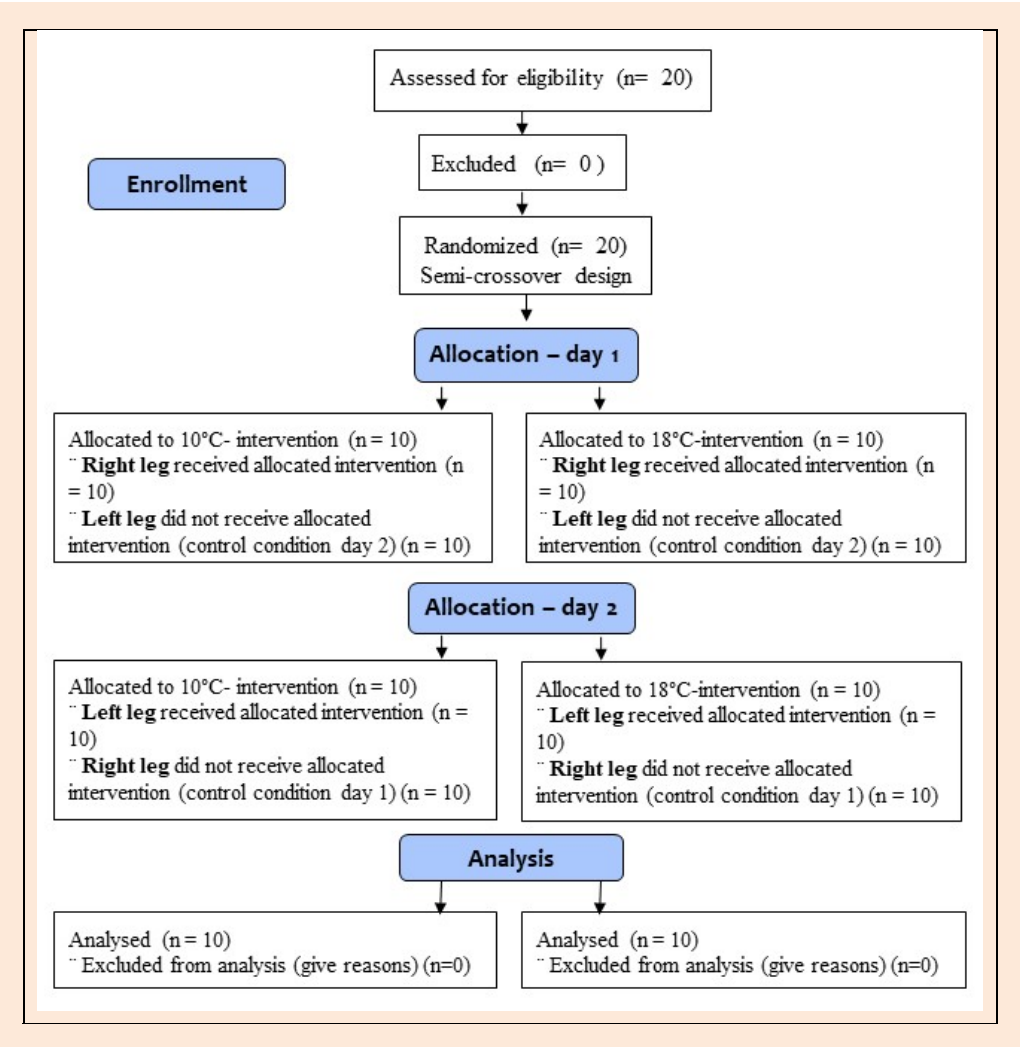

Figure 1. CONSORT Flow diagram.

Six Meter Single Leg Crossover Hop Test for Time (COHT)

The participant was instructed to stand on one leg behind the starting line, then to jump as fast as possible over a distance of 6 meters in a crossover pattern, crossing the centerline with an angle of circa 45 degrees with each hop. The participant was instructed to start at the designated horizontal line. A vertical tape with a length of six meters indicated the centerline. The time required to complete the task was measured in seconds with a standardized handheld stopwatch (Oslo M-427, Robic, Oxford, CT). However, this test is considered to have a poor reliability (Hegedus et al., 2015).

EMG

Skin preparation and sensor location: Before sEMG electrode placement the skin was prepared with an abrasive gel (Nuprep, DO Weaver&Co, Aurora, USA) and cleaned with alcohol to decrease impedance. Two Ag/AgCl surface electrodes (Ambu® Blue Sensor N, N-00S/25) were placed approximately 25 mm apart (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). The EMG sensor placements followed the guidelines of Barbero, Merletti, & Rainoldi (Barbero et al., 2012). Electrode locations were marked on the skin to be able to place them at the same locations on all measurements. A ground electrode was placed on the manubrium sterni.

sEMG data capturing: Surface electromyography (sEMG) was captured during maximal voluntary contraction (MVC) on the M. Vastus Medialis (VM) with pre-amplified surface bipolar EMG sensors (PLUXresearch) [gain 1000, range + 1.5mV with VCC 3V, bandwidth 25-500Hz, input impedance > 100GOhm, common mode rejection rate CMRR 100dB] connected to a wireless bioPLUX research unit with 8 generic analog ports ("Biosignalsplux | Wearable Body Sensing Platform - Biosignalsplux | Wearable Body Sensing Platform"). MVC was performed by each subject in supine position with a foam roller under the

knee and manual resistance against the lower leg. This was performed during 3-5 s with strong verbal encouragement from the researchers and performed twice. A BioSignalsPlux device was used for data capturing and Bluetooth transmission of the signal to a personal computer (interface with OpenSignalsPlux software). Sampling frequency followed the Nyquist theorem which states that to avoid aliasing the sampling frequency should be at least double the upper boundary frequency of interest of 500 Hz in EMG, i.e. a minimum of 1000 Hz. For the wavelet transform the signal length needs to be a power of two, therefore a resampling frequency of 1024 Hz was used. For the sEMG, electrical impedance less than 10 kΩ was considered acceptable.

sEMG data reduction and analysis: The raw sEMG data was processed in Matlab and worked out in a graphical user interface (GUI). Data were processed by means of a Butterworth zero lag 5th order, band pass filtered between 10 and 400 Hz. An amplitude analysis was performed after full wave rectification of the smoothed data and applying a Gaussian blurring filter to cluster the data. From the clustered data the root mean square value (RMS) was calculated. The analysis furthered with a non-orthogonal wavelet approach based on the von Tscharner algorithms (von Tscharner, 2009). Ten non-linearly scaled wavelets covered the frequency band 10-400Hz (Table 2). From the non-orthogonal scalogram, the signal power for each of the different frequency bands was expressed in % of the total power of the complete scalogram.

Table 2. Parameters of the wavelets.

Index of wavelet	Center-frequency (Hz)	Band-width (Hz)
1	6.90	9.77
2	19.29	15.63
3	37.71	21.48
4	62.09	27.34
5	92.36	35.16
6	128.48	41.02
7	170.39	46.88
8	218.08	52.73
9	271.50	58.59
10	330.63	66.41

Statistical methods

For the monitoring of skin temperature, the effects of the temperature (between 10°C vs. 18°C), day (day 1 and day 2), and time (6 time intervals in cooling period) were analyzed with a three-way mixed-measures (2x2x6) ANOVA. For the analysis of the SLHD and COHT, a three-way ANOVA was conducted with temperature (10 and. 18) as between subjects factor and time (pre vs. post) and cooling (cooling vs. no cooling) as within subjects factors. The relative power of the sEMG signal per wavelet band (% of total power) was subjected to the same three-way ANOVA (temperature x time x cooling) with one-dimensional statistical parametric mapping (SPM) (Pataky et al., 2016). SPM allows to examine the entire power distribution within the wavelet domain instead of analyzing each wavelet band separately, thus increasing statistical power and decreasing any potential bias by reverting to a zero-dimensional domain. A statistical analysis of the power in each band separately would ignore the correlation between consecutive bands. The spm1d package (spm1d.org, © T. Pataky) was used for these analyses. When no three-way interactions were present (as was the case in our data), two-way interactions were interpreted. In case of significant two-way interactions with the cooling factor, the analysis was performed separately for the cooled and non-cooled (control) leg. In case of no interaction effects, main effects were interpreted directly. Bonferroni corrections were applied for all post-hoc tests. Because the assumption of normality was not met (examined by Shapiro-Wilk's test) and because of low sample size, inferences from parametric tests were seconded by equivalent non-parametric permutation tests. Significance level was set at $p < 0.05$. All statistical tests were performed in Matlab R2015a.

Results

Skin temperature

Both cooling interventions (10°C and 18°C) were effective in decreasing knee skin temperature ($p < 0.001$). Moreover, skin temperature showed to be significantly different between the 10°C-group (14.84 ± 1.51 °C) and the 18°C-group (21.50 ± 0.79 °C) both throughout and at the end of the cryotherapy intervention ($p < 0.001$). Skin temperature showed no significant differences within groups for day 1 and day 2 ($p = 0.315$).

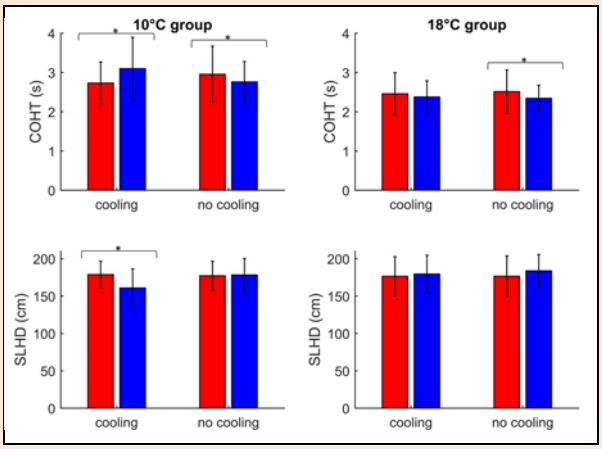

Figure 2. SHLD and COHT-performance. * denotes a significant difference ($p < 0.05$); data are presented as means ± SD

Functional performance

SLHD: The effect of cryotherapy on the outcome of the SLHD is shown in Figure 2. The 10°C-group showed a significant decrease in jump-distance after the application of cryotherapy ($p = 0.0015$, 95% CI [7.802; 7.898]cm, Hedge's $g = 0.795$), while the 18°C-group showed no significant differences ($p = 0.31$).

COHT: As shown in Figure 2, COHT performance significantly deteriorated in the 10°C-group after the application of cryotherapy ($p = 0.0203$, 95% CI [0.064; 0.673]s, Hedge's $g = 0.531$). No significant difference ($p = 0.393$) was found in COHT performance in the 18°C-group after cooling. The overall non-cooling condition significantly ameliorated their COHT performance ($p = 0.003$, 95% CI [0.045; 0.320]s, Hedge's $g = 0.311$), while the 18°C-group

also performed better than the 10°C-group for the non-cooling condition (p = 0.025, 95% CI [0.217; 0.641]s, Hedge's g = 0.777).

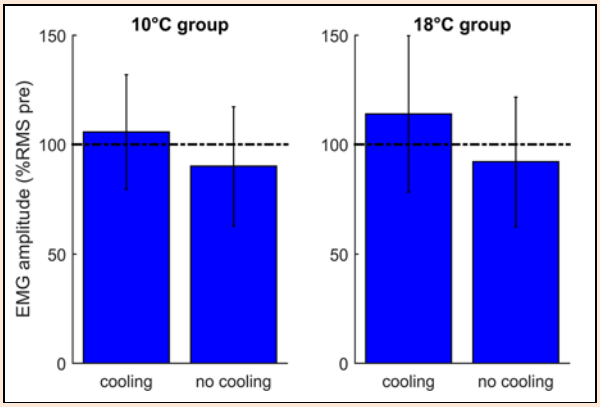

Figure 3. Normalized EMG amplitude (RMS) of the MVC in the 10°C-group and 18°C-group, expressed as percentage of the RMS at pre-test. RMSpre was set at 100% (dashed line). Normalization was performed as follows: [(RMSpost – RMSpre)/RMSpre] * 100%.

EMG

Amplitude analysis: The two-way cooling*time interaction showed a significant effect on EMG amplitude (RMS). The post-hoc analysis was therefore performed separately for the cooled and non-cooled (control) legs. For the cooled condition, no significant interaction effect (temperature*time), or main effect of temperature (F = 0.591; p = 0.452) or time (F = 3.354; p = 0.084) were found. Also for the non-cooled condition, no significant interaction effect (temperature*time), or main effect of temperature (F = 0.033; p = 0.857) or time (F = 2.565; p = 0.127) were present. Figure 3 shows the results of the normalized EMG amplitude (RMS) during the MVC in the cooling and non-cooling conditions.

SPM: The two-way cooling*time interaction showed a significant effect on the distribution of relative power in the wavelet domain. The post-hoc analysis was therefore performed separately for the cooled and non-cooled (control legs). Figure 4 shows the results of the SPM analysis.

Only the main effect of time shows significant effects in the cooling leg only. The first suprathreshold cluster at wavelet bands 1-3 (p < 0.001) indicates significant higher relative power of the EMG signal after cooling, while the second suprathreshold cluster at wavelet bands 5-7 (p < 0.001) indicates significant lower relative power at the post test. From a relative symmetric distribution of power around wavelet band 4, the cooling induces a significant shift of the signal to the lower frequency bands. For the control leg, the symmetry was preserved.

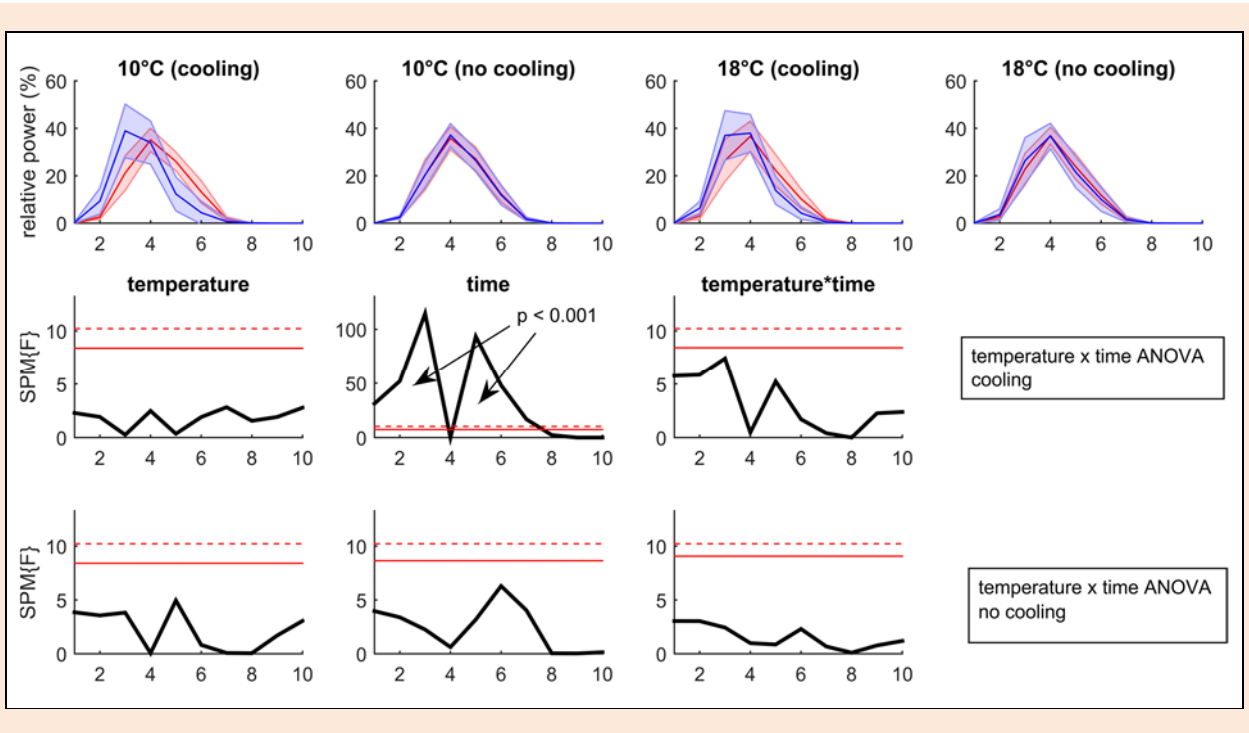

Figure 4. SPM 3-way ANOVA for the MVC. The first row presents the mean (± SD) relative power spectra across the 10 wavelet bands in each condition at pre-test (red) and post-test (blue). Second and third rows present the results of the post-hoc two-way temperature x time ANOVA for cooling and no cooling respectively. Red horizontal lines depict the critical F-values (full line non-parametric, dashed line parametric).

Discussion

The aim of this study was to examine the influence of two existing continuous knee cooling protocols on functional performance and maximal muscular activity. Both continuous knee cooling interventions were successful in reducing skin temperature. The 10°C-intervention was able to reduce knee skin temperature to 14.84 ± 1.51 °C and the 18°C-intervention caused it to decrease to 21.50 ± 0.79 °C. After 1 hour of cooling at 10°C, hop performance deterio-

rated and EMG frequency decreased during MVC, while EMG amplitude showed no changes. However, after a continuous 18°C cooling protocol for 1 hour, hop performance remained largely unaffected, while a clear decrease in EMG frequency and trivial increase in EMG amplitude during MVC was noted. For the non-cooling (control) condition, both groups ameliorated their COHT performance.

The results of both SLHD and COHT performance are in line with previous research. Cross and colleagues (1996) found that a 13°C cold water immersion (CWI) of the lower leg for 20 minutes caused a significant deterioration of vertical jump and shuttle run performance, but a 6-meter hop for time performance did not change after the cooling intervention. This could be explained by the low statistical power and the very short duration of this specific hop test. (Cross et al., 1996). Moreover, Sharma and Noohu (2014) researched the effect of ice massage on lower extremity functional performance tests and weight discrimination ability in collegiate footballers. They selected the SLHD and the single leg crossover hop test for distance as functional performance tests. The ice massage was carried out with an ice cup and was applied at the medial and lateral hamstring tendons for 5 minutes. They found no statistical significant difference in both hop tests and the weight discrimination task. This might be due to the very short cooling intervention (Sharma and Noohu, 2014). In contrast to our study, leg dominance seemed to be an important factor in the design of their study. Preliminary analyses of our data revealed no statistically significant effects of leg dominance or any interaction effects with time or temperature on any of the dependent variables. This finding was in line with the meta-analysis of McGrath et al. (2016). They calculated the effect of limb dominance on isokinetic quadriceps and hamstrings tests, hamstring: quadriceps ratios, SLHD, single leg vertical jump and vertical ground reaction force (resulting from the landing of a single vertical jump), and found pooled symmetry values from 94.6% to 99.6 across these test (McGrath et al., 2016). Furthermore, functional performance tests require and combine many different reductionist aspects of performance (i.e. strength, speed, proprioception, stability, etc.). Cooling may also interact with and affect these components which might superficially explain the deterioration in hop performance in the 10°C-group (Bleakley et al., 2012; Fullam et al., 2015; Furmanek et al., 2014; Montgomery et al., 2015; Patterson et al., 2008). For instance, deceased stability or balance during the landing phase could contribute to the total reduction in hop performance. Montgomery and colleagues (2015) exposed participants to an extensive CWI (from toes till spine) at 12°C for 10 minutes and noted an impairment of balance afterwards. Moreover, Fullam et al. (2015) looked at the effects of local ankle cooling on dynamic postural stability with the star excursion balance test. They selected a continuous cooling device filled with water and crushed ice for 15 minutes, and also found a deterioration of dynamic postural stability.

The EMG frequency changes in response to local cooling (Figure 4) are in line with scientific literature. Even though no significant increase in EMG amplitude was found after cooling, small increases could be observed. Also, trivial decreases of EMG amplitude in the non-cooling condition could be noted (Figure 3), meaning that 1 hour of sitting influences this. Previous findings showed that cooling induced an increase in EMG amplitude and a decrease in EMG frequency components during both isometric and isotonic muscle exercise tests (Holewijn and Heus, 1992; Petrofsky and Lind, 1980; Winkel and Jorgensen, 1991). Recently, Halder and colleagues (2014) found an increased EMG amplitude of the gastrocnemius muscle during a maximal force test after 20 minutes of lower leg CWI (10°C) but found no difference in maximal voluntary isometric performance. However, they did observe a decrease in maximal voluntary isometric performance of the tibialis anterior muscle, but no changes in EMG amplitude were noted (Halder et al., 2014). In general, a possible mechanism behind these increases in EMG amplitude after cooling could be due to the lowered contraction threshold of the fast twitch fibers, which will allow them to be recruited earlier in order to prevent loss of muscle strength at lower temperatures and thus increasing the EMG amplitude for the same workload (Drinkwater, 2008). This might also partly explain why hop performance after the 18°C-intervention was not affected.

Study limitations

A limitation of this experiment is that no familiarization trial was performed prior to data collection. A learning effect occurred in the non-cooling condition of the COHT during the experimental trials together with a randomization bias, since the 18°C-group performed substantially better than participants from the 10°C-group in the non-cooled condition. The COHT data for the cooling condition clearly showed that participants exposed to 10°C became significantly slower ($p = 0.0203$, 95% CI [0.064; 0.673]s, Hedge's $g = 0.531$), while for the 18°C-exposure no difference ($p = 0.393$) in COHT performance were noted . In contrast, the COHT data for the non-cooling condition in both groups revealed that participants became significantly faster ($p = 0.003$, 95% CI [0.045; 0.320]s, Hedge's $g = 0.311$). Nevertheless, all data of the other control conditions (SLHD, EMG) showed no occurrence of such biases.

Another limitation of this study was that we were not able to measure internal limb temperatures at muscle level. This would have given more insight on muscle temperature changes in response to continuous cooling at a given temperature, and could have led to a better understanding of interactions between muscle temperature changes, neuromuscular activity and functional performance.

Practical application and future research

Computer controlled continuous cooling devices are on the rise, especially in the clinical setting (e.g. physiotherapy, orthopedics), and provide several benefits in comparison to conventional cooling methods. Local pre-cooling is most applicable in the clinical setting, as patients are often cooled prior to exercise therapy. In specific patient populations, pre-cooling might even have a positive effect on (post-operative) rehabilitation outcomes. For instance, in order to overcome arthrogenic muscle inhibition in post-

operative patient (e.g. anterior cruciate ligament injury reconstruction). Greater strength gains have been observed in anterior cruciate ligament injury reconstruction patients when applying cryotherapy prior to strength training (Hart et al., 2014). Future research should therefore focus on patient populations and include possible functional performance outcomes to explore if pre-cooling interventions can contribute to the improvement of more complex movement skills beyond muscle strength gains. Nevertheless, this study showed that prolonged aggressive cooling (10°C) before commencing exercise cannot be recommended due to its related negative effects on performance and its relatedness to an increased injury risk hypothesis. However, an intensive one hour 18°C-cooling protocol seems to have no harmful effects on functional hop performance. This being said, caution is still warranted after exposing people to a prolonged mild cooling intervention.

Conclusions

Continuous knee cooling at 18°C for one hour does not affect functional hop performance, though adaptations at the muscle level (EMG frequency decrease) can be observed. Nevertheless, applying continuous cryotherapy to the knee for one hour with a temperature of 10°C results in a significant decrease in functional hop performance and EMG frequency, while EMG amplitude did not increase significantly. This infers that changes at muscle level due to local temperature manipulations may not always be detrimental in regard to functional performance. However, caution is warranted when exposing healthy subjects to local cooling prior to exercise. Future research should focus on pre-cooling in patient populations, as some evidence shows a beneficial influence on rehabilitation outcomes.

Acknowledgements

No authors declare conflicts of interest. The study complied with the laws of the country of the authors' affiliation.

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Key points

- Continuous one hour knee cooling at 18°C does not affect functional performance.
- However, continuous one hour knee cooling at 18°C causes adaptations at the neuromuscular level.
- Continuous one hour knee cooling at 10°C results in a significant decrease in functional performance, as well as in neuromuscular activity of the quadriceps.
- Changes at the neuromuscular level due to continuous, local cooling may not always be detrimental to functional performance.

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