International Journal of Sports Physiology and Performance, 2021, 16, 682-687
https://doi.org/10.1123/ijspp.2020-0191

Human Kinetics
ORIGINAL INVESTIGATION

Effect of Acute Interset Foot Cooling on Lower Limb Strength Training Workout

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Purpose: The authors investigated the effect of foot cooling (FC) between sets in a leg press pyramid workout with resistance-trained participants. ***Methods:*** A total of 12 resistance-trained men (age = 21.8 [0.6] y; training experience = 1.7 [1] y) performed a pyramid workout, including 4 sets of 85% to 90% 1-repetition maximum leg press exercise to exhaustion with interset FC or noncooling in a repeated-measures crossover design separated by 5 days. The authors immersed the participants' feet in 10°C water for 2.5 minutes between sets. ***Results:*** Two-way repeated-measures analysis of variance revealed that FC elicited significantly higher repetitions and electromyography (EMG) values of the vastus lateralis (simple main effect of condition) than did noncooling ($P < .05$) in the second (repetitions: 11 [3.5] vs 7.75 [3.2]; EMG: 63.4% [19.4%] vs 54.5% [18.4%]), third (repetitions: 8.9 [3.2] vs 6.4 [2.1]; EMG: 71.5% [17.4%] vs 60.6% [19.4%]), and fourth (repetitions: 7.5 [2.7] vs 5.1 [2.2]; EMG: 75.2% [19.6%] vs 59.3% [23.5%]) sets. The authors also detected a simple main effect of set in the FC and noncooling conditions on repetitions ($P < .05$) and in the FC condition on the vastus lateralis EMG values. Although the authors observed no time × trial interactions for the rating of perceived exertion, the authors observed main effects on the sets (7.7–9.6 vs 7.9–9.3, $P < .05$). ***Conclusions:*** Interset FC provides an ergogenic effect on a leg press pyramid workout and may offset fatigue, as indicated by higher repetitions and EMG response, without increasing perceived exertion.

Keywords: pyramid workout, electromyography, leg press, cold immersion

Competitive sports that emphasize strength and power often incorporate resistance exercise into routine training programs. During high-intensity resistance exercise sessions, the exercise volume accomplished at a given intensity, which often represents repetitions completed per set, is linked to long-term muscle strength improvement.[1–3] Experienced athletes who have been following a structured resistance training program for a long time only left little room for improvement.[3] For these athletes, exploring accessible strategies for effectively amplifying resistance exercise response may be valuable for maximizing individual potential.

Cooling active muscles between sets has been demonstrated to produce an ergogenic effect during intense resistance exercise. It augments repetitions per set, increases weights lifted, and delays fatigue.[4,5] However, other studies have determined that cooling intervention reduces isometric strength[6] and isokinetic strength both concentrically and eccentrically[7] and reduces explosive strength, such as in vertical jump and shuttle run performance.[8] Researchers have speculated that cooling active muscles may elicit vasoconstriction, which reduces the release of calcium from the sarcoplasmic reticulum, thus impairing crossbridge formation.[7] It may also impede the sensitivity of the neuronal discharge and diminish the sensitivity of muscle spindles, which in turn, affects muscle contractile function.[8]

In addition to the direct cooling of active muscles attenuating performance, emerging topics have focused on cooling peripheral extremities. Researchers have demonstrated that cooling the palms, feet, or distal joints of the active muscles benefits neuromuscular function and performance.[1,9–14] Although the exact mechanism is not clear, it appears that delaying fatigue[1,11,14] and activating peripheral afferent stimulation by increasing reflex and muscle excitability in central nervous system (CNS) processing may be relevant to the proposed factors.[9,10,12,13] With a 4-set 8-repetition of concentric leg press at a submaximal level of effort on a flywheel ergometer, researchers have demonstrated that applying an interset palm cooling intervention hastened blood lactate clearance and delayed the average power decrements.[11] In addition, other studies have assessed the effect of palm cooling on a bench press workout. The researchers asked resistance-trained participants to perform 4 sets at 85% of their 1-repetition maximum (1RM) load for the bench press. They applied interset palm cooling for 2.5 minutes. The results indicated that the repetitions, total exercise volume, and electromyography (EMG) amplitude of some muscles were significantly higher; even the degree of rating of perceived exertion (RPE) was significantly lower than that of the participants in the noncooling (NC) condition.[9,10]

Interset palm cooling yielded an ergogenic effect on high-intensity bench press workouts and on leg press exercise using a flywheel ergometer. However, whether resistance-trained individuals performing lower limb resistance exercise in a pyramid workout, typically done with higher repetitions with lower load for the first set and then with the addition of load while reducing the number of repetitions in the following sets (a common regime for those seeking strength gains),[1–3] benefit from peripheral cooling (ie, the feet) is unknown. Therefore, we investigated the effects of interset foot cooling (FC) on a leg press pyramid workout. We hypothesized that interset FC increases total exercise volume, amplifies EMG amplitude, and reduces RPE values during multiple sets of a leg press pyramid workout.

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Methods

Participants

In total, 12 healthy men (age = 21.8 [0.6] y, height = 175.6 [6.4] cm, body mass = 74.6 [12.5] kg, leg press 1RM: 163.7 [20.9] kg) participated in this study. The participants had performed regular resistance training (training experience = 1.71 [1] y; ratio of weight pressed to body weight = 2.2 [0.3]) 2 or more times per week prior to the study. We excluded individuals if they had been injured in the previous 6 months, had more than 2 risk factors as outlined by the American College of Sports Medicine,[15] and reported taking ergogenic supplements or medicine that could affect exercise performance. We asked the participants to maintain their usual diets during the study but to refrain from strenuous exercise, caffeine, and alcohol 24 hours before each trial and a preworkout meal 2 hours before each condition. We received written informed consent from all participants after we provided verbal and written explanations of the experimental procedure, potential risks, and benefits of the study. We conducted the study in accordance with the Declaration of Helsinki, and the Institutional Review Board of National Cheng Kung University Hospital approved it (NCKU HREC-E-108-080-2).

Experimental Design

We adapted the study design largely from Kwon et al,[9,10] who applied palm cooling between high-intensity bench press sets. Our study had 3 experimental days: 1RM leg press testing day (Day 1) followed by 2 exhaustive leg press pyramid workouts with or without interset FC performed in a counterbalanced-order repeated-measures design (Figure 1). We separated the 3 experimental days by 5-day intervals. The 1RM testing day entailed familiarization with study procedures, collection of individuals' anthropometric data, and verification of their resistive load with the 1RM leg press test, followed 5 minutes later by one set at 85% of 1RM to exhaustion. During the 2 exhaustive leg press days, the participants performed the same 1 set of 85% 1RM as performed on Day 1, but they also performed 3 additional exhaustive sets at 85%, 87.5%, and 90% of 1RM, with or without interset FC. We obtained dominant lower limb EMG data during the leg press exercise and sole skin temperature and RPE data between sets. All experiments were performed in a normothermic room, which was maintained at 24°C to 26°C and 40% to 60% humidity, and at the same time of day for each participant. All training sessions were conducted under the strict, direct supervision of an individual familiar with technical resistance training. The study lasted from April to May.

Intervention Conditions

The cooling method with cold-water immersion has been applied in many studies.[14,16] In the current study, the participants immersed their feet up to the distal end of the fibula (lateral malleolus) in buckets filled with water controlled at 10°C (1°C). We monitored the water temperature throughout the FC condition and maintained the target temperature by adding crushed ice when required.[16] We chose this temperature based on hand immersion research indicating that it is optimal and causes limited vasoconstriction in the hand.[9,10] For the FC condition, the water cooled the feet for 2.5 minutes during each rest period after the first 85% of the 1RM set. The NC condition involved placing the feet in the buckets but without the application of cold water.

1RM and One Set of 85% of 1RM Exhaustive Test

We assessed 1RM strength on a resistance machine (Leg Press G3-S70; Matrix, Taipei, Taiwan). We instructed the participants to adjust the seat carriage to set the knee angle at 90°. We marked the positions of the feet on the pedal to ensure identical step distance during all tests. Then, the participants squeezed the grips and pushed away the given load until their legs were straight while their head, shoulders, back, and buttocks remained in contact with the pad.

We determined 1RM strength as in relevant studies.[9,10,17] The standardized warm-up included ten repetitions at 50% of (predicted) 1RM, 5 repetitions at 70% of 1RM, 3 repetitions at 80% of 1RM, and 1 repetition at 90% of 1RM, followed by 3 attempts to determine the participant's actual 1RM. We recorded the heaviest weight successfully completed as 1RM. The duration of the rest period was 3 minutes of rest between sets. After the 1RM test, the participants had a 5-minute rest period and then performed as many repetitions as possible using 85% of 1RM. Similarly to the studies of Kwon et al,[9,10] the 85% 1RM test served as a baseline value before the intervention condition during each exhaustive leg press pyramid workout.

Exhaustive Leg Press Pyramid Workouts

The standardized warm-up included 10 repetitions at 50% of 1RM, 5 repetitions at 70% of 1RM, 3 repetitions at 80% of 1RM, and

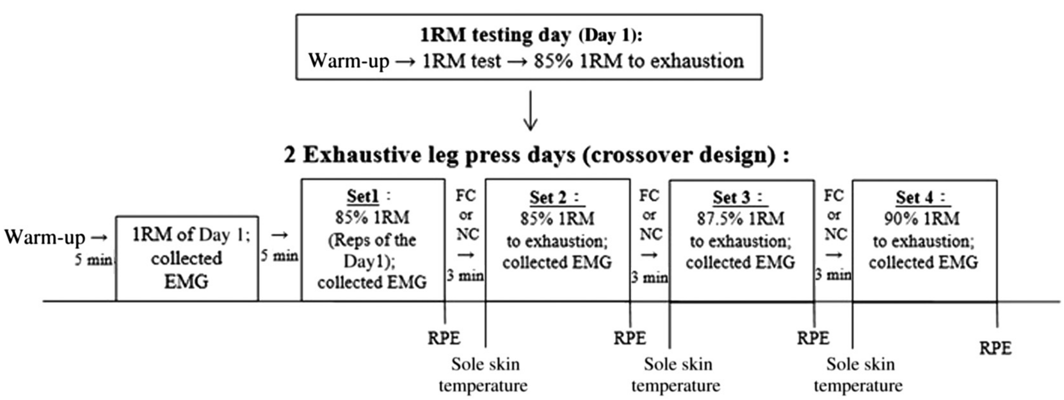

Figure 1 — Schematic of the experimental design. Procedures for 1RM testing and 4 sets of leg press exercises in FC and NC conditions, including a schedule of parameters collected. EMG indicates electromyography; FC, foot cooling; NC, noncooling; 1RM, 1-repetition maximum; RPE, rating of perceived exertion.

1 repetition at 90% of 1RM, with 3 minutes of rest between sets. After 5 minutes, the participants completed their 1RM of Day 1. We collected 1RM EMG data throughout for normalization purposes, because the EMG signal from the muscle surface varies from one location to another; thus, the absolute EMG signal cannot be compared between separate days.[9,10] After another 5 minutes of rest, the participants completed one set of 85% of 1RM as performed on Day 1 and 3 additional sets at 85%, 87.5%, and 90% of 1RM until exhaustion. Between each set, the participants rested for 3 minutes. The 3-minute rest periods between sets 2, 3, and 4 consisted of a 15-second transition from the exercise to the treatment, 2 minutes 30 seconds of FC or NC condition, and another 15 seconds of transition from the rest period to the next set. We measured sole skin temperature when the participant was ready to begin the next set. We used the Borg CR-10 scale to measure the participants' RPE immediately after each set. We collected EMG data throughout the 4 sets (Figure 1).

Sole Skin Temperature

An infrared skin thermometer (DT-8380; Deryuan, New Taipei, Taiwan) was used to measure sole skin temperature. We positioned the probe of the thermometer 0.5 cm from the skin and read the temperature at 1 second on the thermometer display.

EMG Signal Analysis

We attached surface electrodes on the belly of 2 muscles of the dominant lower limb, namely the vastus lateralis (VL) and gastrocnemius (GS), and the ground electrode was placed over the epicondyle of the tibia after we shaved, abraded, and cleaned the participant's skin with alcohol to minimize impedance. A Noraxon Telemyo DTS EMG system (Noraxon, USA, Inc) collected, amplified (×1000), and bandpass-filtered the EMG signals at 10 to 500 Hz (2%) cutoff (Butterworth/Bessels; an anti-aliasing low-pass filter). To evaluate the motor unit requirements, raw EMG signals were processed as the root mean square (RMS) values and were full-wave rectified and low-pass filtered (12 Hz) over the given periods. Then, the RMS values of the EMG signals were normalized to the 1RM EMG value according to the isolated 1RM performed before each condition. Subsequently, the RMS EMG values for the VL and GS were expressed as percentage 1RM.

Statistical Analysis

The data are expressed as the mean (SD). Total exercise volumes (sets × repetitions × weight) between conditions were compared using a paired t test. A 2-way repeated-measures analysis of variance test was used to quantify the differences in sole skin temperature, repetitions per set, RMS EMG values, and RPE between conditions and sets. Significant condition × set interactions were followed up with simple main effects analyses and, in cases where no significant interaction was found, we used least significant difference (LSD) post hoc tests to follow up the significant main effects for each condition and set. The statistical significance was set at $P < .05$.

Results

Sole Skin Temperature

We observed no condition × set interaction ($F = 2.274$, $P = .127$, effect size [ES] = 0.171) or main effect of set ($F = 3.329$, $P = .055$, ES = 0.232) on sole skin temperature. However, we identified a significant main effect of condition ($F = 870.551$, $P < .001$, ES = 0.988), with the sole skin temperature being lower in the FC condition than in the NC condition (19.4°C [0.4°C] vs 34.5°C [2°C]; Figure 2).

Repetitions

We identified a significant condition × set interaction ($F = 4.663$, $P = .008$, ES = 0.298), a significant main effect of condition ($F = 11.292$, $P = .006$, ES = 0.507), and a significant main effect of set ($F = 16.705$, $P < .001$, ES = 0.603) on repetitions. A simple main effect of condition was found on the second (11.0 [3.5] vs 7.8 [3.2]; $F = 8.489$, $P = .014$, ES = 0.436), third (8.9 [3.2] vs 6.4 [2.1]; $F = 6.496$, $P = .027$, ES = 0.371), and fourth sets (7.5 [2.7] vs 5.1 [2.2]; $F = 10.573$, $P = .008$, ES = 0.49). We also detected a simple main effect of set in the FC ($F = 9.9$, $P < .001$, ES = 0.474) and NC conditions ($F = 12.89$, $P < .001$, ES = 0.54; Figure 3). Pairwise comparisons revealed that, in the FC condition, the number of repetitions was greater in the second and third sets than in the first

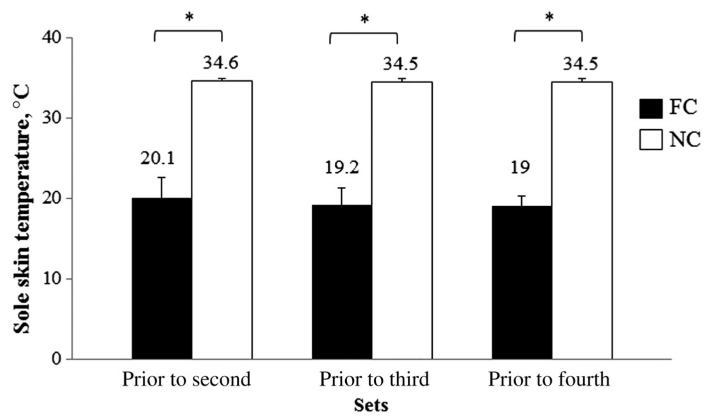

Figure 2 — Sole skin temperature data obtained during rest periods in a leg press workout in FC and NC conditions (mean [SD]). *Significant difference between FC and NC. FC indicates foot cooling; NC, noncooling.

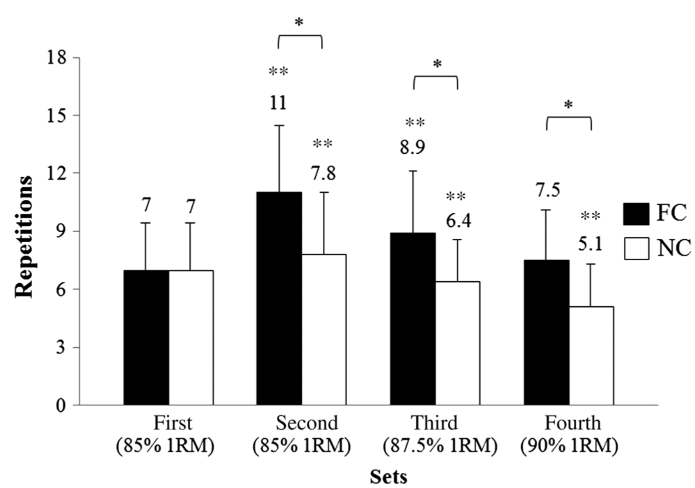

Figure 3 — Repetitions data from a leg press workout in FC and NC conditions (mean [SD]). *Significant difference between FC and NC. **Significant difference compared with the first set. FC indicates foot cooling; NC, noncooling; 1RM, 1-repetition maximum.

set ($P = .002$ and .036, respectively), whereas in the NC condition, only the number of repetitions in the second set was significantly higher than in the first set ($P = .043$).

Total Exercise Volume

Overall, total exercise volume with FC (4774.7 [1032.6] kg) was significantly higher ($t = 3.599$, $P = .004$, ES = 1.259) than that with NC (3674.7 [1225.5] kg).

Electromyography

We observed a significant condition × set interaction ($F = 2.922$, $P = .048$, ES = 0.21), a significant main effect of condition ($F = 5.029$, $P = .046$, ES = 0.314), and a significant main effect of set ($F = 6.133$, $P = .002$, ES = 0.358) on the RMS EMG (in percentage) values of the VL. A simple main effect of condition on the second (63.4% [19.4 %] vs 54.5% [18.4%]; $F = 5.098$, $P = .045$, ES = 0.317), third (71.5% [17.4%] vs 60.6% [19.4%]; $F = 4.74$, $P = .052$, ES = 0.301), and fourth sets (75.2% [19.6%] vs 59.3% [23.5%]; $F = 5.733$, $P = .0036$, ES = 0.343) was identified. We observed a simple main effect of set only in the FC condition ($F = 7.583$, $P = .001$, ES = 0.408). Pairwise comparisons revealed that the RMS EMG (in percentage) values of the VL in the second, third, and fourth sets were significantly higher than in the first set ($P = .007$, .001, and .003, respectively; Figure 4A).

We identified no condition × set interaction ($F = 0.651$, $P = .588$, ES = 0.056) or main effect of condition ($F = 3.794$, $P = .077$, ES = 0.256) on the RMS EMG (in percentage) values of the GS. However, we observed a significant main effect of set ($F = 3.229$, $P = .035$, ES = 0.227), with the RMS EMG (in percentage) values of the GS being higher in the fourth set than in the first ($P = .015$) (Figure 4B).

Ratings of Perceived Exertion

We observed no condition × set interaction ($F = 2.078$, $P = .122$, ES = 0.159) or main effect of condition ($F = 0.041$, $P = .843$, ES = 0.004) on the RPE values. We observed only a significant main effect of set ($F = 24.986$, $P < .001$, ES = 0.694). Figure 5 presents the results of the LSD post hoc comparison.

Discussion

Only a few studies have investigated peripheral instead of active muscle cooling during resistive exercise. To our knowledge, this is the first study to examine interset FC on a leg press workout. Furthermore, we employed a pyramid workout, which is a more common regime for those seeking strength gains. The principal finding of this study was that a leg press workout performed with interset FC reduced the sole temperature and increased the number of repetitions completed per set, total exercise volume, and RMS EMG of the VL without increasing the degree of RPE.

Previous findings indicated that intermittent palm cooling between bench press sets reduced palm temperature.[9,10] The current study corroborates the cooling effects and found that, under normothermic conditions, a similar cooling protocol (10°C for 2.5 min) on the foot between sets successfully reduced the sole temperature. Moreover, the interset FC increased the total leg press exercise volume compared with the NC condition. This finding supports previous research demonstrating that palm cooling between a leg press exercise on a flywheel ergometer elicited greater power output than NC.[11] Also, the current findings are similar to those previously reported by Kwon et al,[9,10] who indicated that interset palm cooling increased total exercise volume during a bench press workout for resistance-trained male and female participants. Likewise,[9,10] after the first set, when we applied the FC intervention, the repetitions were higher in the following sets with FC, even when the participants performed a higher intensity pyramid workout (Figure 3). In our leg press pyramid workout, the participants performed an incremental resistance exercise, set by set. In the NC condition, one can expect to observe trends of decreasing repetitions as the sets progress (Figure 3). Surprisingly, in the FC condition, the number of repetitions was higher in the second and third sets; even the intensity was maintained or increased after the intervention (Figure 3). Given that previous investigations did not observe higher repetitions in the sets following the first (in a palm cooling condition),[9,10] the results imply that interset peripheral cooling may be more evident in larger muscle group contracting against gradual progress resistance to near-maximal weights that elicit

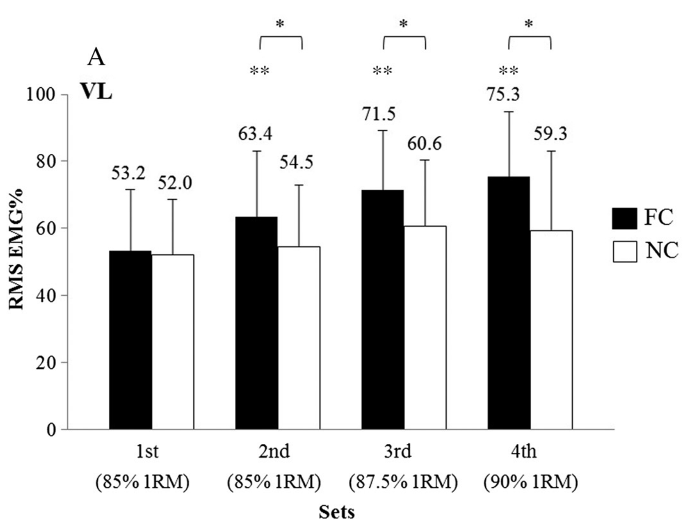

Figure 4 — RMS EMG values of the VL (A) and GS (B) during a leg press workout in FC and NC conditions (mean ± SD). *Significant difference between FC and NC. **Significant difference compared with the first set. EMG indicates electromyography; FC, foot cooling; GS, the gastrocnemius; NC, noncooling; RMS, root mean square; VL, the vastus lateralis; 1RM, 1-repetition maximum.

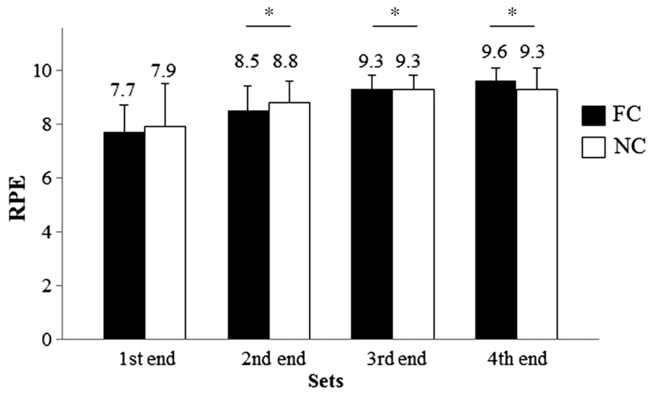

Figure 5 — RPE values obtained at the end of sets during a leg press workout in FC and NC conditions (mean [SD]). *Significant difference compared with the first set. FC indicates foot cooling; NC, noncooling; RPE, rating of perceived exertion.

greater absolute force. The mechanisms by which force output increases following peripheral cooling are not clear. It has been reported that the arousal level aided in increasing the number of repetitions per set during a high-intensity resistance exercise workout[18] and increased maximal strength.[19] Peripheral cooling to a joint instead of the muscle has been demonstrated to increase plasma norepinephrine,[12] which is secreted by the CNS and plays a key role in enhancing the arousal level.[20] Taken together, these lines of evidence suggest that arousal may act as a clue to how peripheral cooling exerts its effect on force output under normothermic conditions.

Regarding the effect of peripheral cooling on neuromuscular activation, it may act as an afferent stressor to CNS processing that adjusts the motor output of the contracting muscles[9,10] and facilitates motor neuron excitability of a given task (as detected by the H-reflex and M-response measurements).[12,13] In the FC condition, we observed higher RMS EMG values in the VL in the sets that followed FC. Furthermore, RMS EMG values of the active VL, which occupies the primary role in a leg press, were higher in the FC than in the NC condition (second to fourth sets), although the participants lifted the same weight in each set in both conditions. Notably, the higher RMS EMG values for the primary agonist muscle with FC were concomitant with a greater number of repetitions (Figures 3 and 4A). Our interpretation of the result is that, after the FC intervention, the numbers of repetitions in each set were higher than in the NC condition, indicating that the physiological upper limit had been exceeded by FC. Therefore, in the last few repetitions of each set of the FC condition (the additional number of repetitions compared with the NC condition), the participants may have been on the verge of volitional exhaustion fatigue. Under the circumstances of nearly approaching fatigue, additional motor units may be recruited to compensate for the loss of exerted force[21,22] and thus increase the RMS EMG. However, the GS, which is proximal to the foot (compared with the VL), did not magnify the RMS EMG response during a leg press workout with FC, suggesting that GS was sufficient to maintain neural drive during the leg press movement, although cooling was applied. The results differ from the findings of other studies that found cooling the joint increased the excitability of the nearby muscle.[12] Methodological differences (EMG vs M-wave) and the fact that GS is not the primary agonist muscle during the leg press may account for certain puzzling findings. It would appear that the peripheral afferent cooling stimuli transfer to CNS processing during resistance exercise may modulate the motor output to the primary agonist muscle rather than the synergistic muscle, although it is approaching the cooling region. Our results support those reported by Kwon et al,[9,10] who found that interset palm cooling increased the RMS EMG values of some primary agonist muscles during a bench press workout, and we extend these findings to lower limb exercise at a higher intensity.

Resistance exercise at higher intensity and volume often results in greater force development, which may cause a greater degree of fatigue.[23] Notably, after a palm cooling intervention, higher repetitions with lower RPE values were found at the initial set (but not the following sets) of a bench press workout.[9] This suggests that cooling may possess the potential to delay fatigue during heavy resistance exercise. Somewhat inconsistently with an earlier investigation,[9] we did not find a significant difference in RPE values between FC and NC conditions in any set. Because the increased exercise volume (29%) with FC in our study did not produce a substantial effect on RPE scores, the FC condition evokes greater work, but it is not sensed as such, thus eliciting RPE values equal to those in the NC condition. Taken together, we speculate that interset FC may, at least in part, counteract some aspect of the perception of increased effort. The overriding sensations of fatigue resulted in the same degree of perception of effort at volitional exhaustion.

We must mention limitations regarding the interpretation of this study. Because the participants in this study were trained, the results might not be appropriate for extrapolation to populations who are physically inactive or novice lifters. Furthermore, the resistance exercise session employed in our study only focused on a single exercise; therefore, the findings might not be considered fully representative of the multiple exercises that athletes typically apply in a resistance-training session. Therefore, additional studies are warranted to better understand whether peripheral cooling between sets would provide an ergogenic effect on a resistance training program that incorporates multiple exercises.

Practical Applications

If resistance-trained individuals wish to enhance leg-strength-training effects, they can apply interset FC to magnify the training stimulus during a pyramid workout.

Conclusions

Interset FC during a leg press pyramid workout by resistance-trained men resulted in increased repetitions to exhaustion and exercise volume, as well as a more pronounced activation of the primary agonist of the lower limb without increasing perceptions of fatigue. These results suggest that interset FC may provide an ergogenic effect on training responses.

Acknowledgments

The authors would like to thank all the participants involved in the study for their contribution.

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