No Effect of Interset Palm Cooling on Acute Bench Press Performance, Electromyography Amplitude, or Spectral Frequencies in Resistance-Trained Men

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Abstract:

Previous research has suggested that cooling distal to the working agonist muscles during the inter-set rest periods of high-intensity resistance exercise may facilitate improved performance through increased agonist activation. However, these studies have used inappropriate EMG normalisation techniques. Therefore, the aim of this study was to compare two palm-cooling conditions to a thermoneutral condition during high-intensity resistance exercise and subsequent effects on exercise performance, EMG amplitude and spectral frequencies using appropriate normalisation methodologies**.** Eleven healthy, resistance-trained, young males (20-36 years old) performed four sets of bench press exercise to exhaustion at 80% 1RM each separated by three minutes of passive recovery. Palm-cooling (10^{o}C [TEN] or 15^{o}C [FTN]) or thermoneutral (28^{o}C [CON]) conditions were applied for sixty seconds during the recovery interval of each set in a randomised, double-blind fashion, with four days recovery between experimental conditions. Palm temperature was significantly lower ($p<0.05$) in the TEN and FTN conditions compared to CON. Number of repetitions and mean power in the bench press declined significantly following each set in all conditions ($p<0.05$). There were no significant differences ($p>0.05$) in any bench press performance or EMG-related variables between any of the conditions. Palm cooling at either 10 or 15^{o}C had no effects on bench press performance compared to a thermoneutral condition, with no observable effects on neuromuscular responses during exercise. Therefore, cooling is not currently recommended as an ergogenic strategy to enhance acute bench press performance during high-intensity resistance training.

Key words: conduction; convection; mean frequency; median frequency; muscle; agonist

INTRODUCTION:

Resistance training-induced hypertrophy is a contributory cause of strength gain in skeletal muscle(29), which is a fundamental aspect underpinning sports performance(28). Of the multiple resistance training variables that can be manipulated in order to induce an increase in muscle mass, one of the most basic yet important is exercise volume, i.e. the total amount of work performed by the muscle(s). A recent meta-analysis demonstrated that there is a dose-response relationship between resistance training exercise volume and increases in muscle mass(27), and that exercise volume may be the most effective variable to manipulate for skeletal muscle hypertrophy(9). One potential intervention that has received some, yet limited investigation in exercise science, is that of cooling (application of a cooling device or material/substance directly to an agonist muscle or to its distal joint) and its acute ergogenic effect on resistance training volume.

A review by Kwon et al.(19) found that whilst longer term (≥3mins) local pre-cooling of muscle had a negative effect on performance, short term interval cooling during resistance exercise (≤3mins) had a positive effect on short duration, high intensity resistance exercise performance. One of the methods employed in these interval cooling studies involves cooling distal to the agonist muscle, for example palm or sole cooling during upper or lower body resistance exercise respectively, as opposed to previous methods of direct application of cooling over the agonist muscle. In two previous studies, Kwon et al.(17, 18) applied palm-cooling at 10^oC during the 3-minute rest periods of 4 sets of repetitions to exhaustion at 85% 1-repetition maximum (1RM) of the bench press exercise, and analysed the electromyography (EMG) amplitude of the pectoral, anterior deltoid and triceps brachii muscles. This resulted in a significantly greater number of repetitions and total exercise volume than a control (thermoneutral) condition in resistance trained men and women. The studies also reported a decreased rating of perceived exertion (RPE; men only) and increased percentage difference in EMG amplitude of the triceps and/or anterior deltoids in the cooling condition compared to control, indicating a potential reduced perception of effort and increased muscle activation. In a similar fashion, sole-cooling during the inter-set rest period by foot immersion in 10°C of water during a leg press pyramid workout elicited a greater number of repetitions and Vastus Lateralis EMG amplitude compared to non-cooling control(3). However, despite this evidence, ergogenic effects of distal inter-set cooling during resistance exercise have not been shown to be universal. Batra et al.(1) showed that sole cooling to 10°C during rest periods between 4 sets of squats to exhaustion had no significant effects on repetitions performed, exercise volume or muscle activation.

It has been purported that the main potential mechanism underlying the ergogenic effect of distal cooling is neural in origin. Sensory stimuli such as cooling can alter or block the transmission of afferent signals via the central nervous system (CNS) to the brain that may eventually be perceived as 'pain', which may permit maintenance of exercise performance. Previous studies have pointed to the root mean squared (RMS) EMG amplitude and spectral data being greater in cooling conditions than thermoneutral conditions as evidence of a neural mechanism, such as reduced inhibition of neural drive (3, 17-19). Submaximal EMG amplitude at task failure is mainly influenced by a decrease in the number of muscle fiber action potentials. This decrease in synaptic input, in relation to non-fatigued conditions, has been attributed to a decrease in afferent feedback levels (6). Therefore, the neural mechanism for the apparent benefits of cooling during submaximal contractions requires further investigation. Additionally, on inspection of the EMG methodologies employed in studies that showed an enhanced muscle activation following cooling versus a thermoneutral condition, there are some important considerations/limitations evident. Firstly, in the studies of Kwon et al.(17, 18) and Cai et al.(3), the authors use the task performance (bench press 1RM and leg press 1RM respectively) prior to each condition as their method of EMG signal normalization. However, contemporary EMG methodologies suggest this is inappropriate, as the activation level needed to produce the force associated with a dynamic 1RM reference task may not reveal how active a muscle is in relation to its maximal activation capacity(2). Also when comparing multiple trials across days, individuals may use different muscle control strategies to produce the same movement(12), thus rendering a 1RM dynamic task inappropriate for these study designs. Instead, a more appropriate method is to incorporate a maximal voluntary isometric contraction (MVIC) as the reference normalization method(12). Secondly, whilst performing their spectral analysis, Kwon et al.(17, 18) also normalized the mean and median frequency data to the 1RM task performance. In a spectral analysis, changes in the shape of the power density function of the EMG are of importance because muscle fatigue results in the downward shift of the frequency spectrum possibly due to modulation of recruitment firing rates or slowing/grouping conduction velocity(26). Thus, normalization of the mean or median frequency to a maximal reference task is not recommended(12, 26). Thirdly, the studies of Kwon et al.(17, 18) used the percentage difference in EMG amplitude between the first repetition of the first set and the final repetition of the final set as evidence of neural function. Variability between single EMG readings are high on both an intra and inter-individual basis(23), and is likely to be higher under local muscle fatigue(20, 25). Controlling for variations in EMG amplitude between trials and days is one of the most challenging aspects of EMG methodologies(23). Therefore, the potential for error in assessing only two individual electromyograms per condition, per person, separated by at least 3 days, is high and such practices are not advised. Taking these limitations together, the assertion that previous studies have provided sufficient evidence to a neural mechanism are premature, and warrants further investigation using appropriate methodologies.

Grahn et al.(11) studied the longer term effects of repeated palm cooling application of 15^{o}C over a 3-6 week resistance training program on bench press performance, pull-up performance and strength. The authors showed that the cooling intervention resulted in a significantly greater post-training acute exercise volume, although strength gains (1RM) were similar to those seen in the control group. Therefore, it appears that palm cooling at both 10^{o}C and 15^{o}C may potentially provide an ergogenic effect for improving resistance exercise performance. However, to date no studies have directly compared the effects of inter-set cooling using both 10^{o}C or 15^{o}C, compared to a control (thermoneutral) condition. Therefore, the aim of the current study is to investigate the acute effects of palm cooling on high intensity bench press performance during subsequent sets, and EMG characteristics of the pectoral, anterior deltoid and triceps brachii muscles using appropriate EMG methodologies. Specifically, the study will compare the effects of cooling at both 10^{o}C and 15^{o}C compared to a control (thermoneutral) condition on bench press performance and agonist muscle activation.

METHODS:

Experimental Approach to the Problem

The study used a within-subjects, randomized, controlled, counterbalanced design in order to effectively assess differences in bench press performance variables and muscle activation under three different conditions. Participants completed a traditional resistance training protocol of four sets of bench press exercise at 80% 1RM to volitional exhaustion in each set, interspersed by three minutes of passive recovery. Exercise load, tempo, inter-set recovery duration and inter-set condition application duration were all controlled throughout the study; therefore the inter-set recovery condition (independent variable) was the only altered variable between laboratory sessions. Palm cooling or thermoneutral (control) conditions were employed for 60 s during the inter-set recovery period. The study design, loading scheme and protocol used are largely replicative of those already evident in cooling literature. The dependent variables recorded were number of repetitions completed and power via a linear position transducer for bench press performance. Also, muscle activation via EMG amplitude and spectral frequencies were accessed from the bench press exercise agonist/synergist muscles (pectorals major, anterior deltoid, triceps brachii).

Participants:

An a priori sample size calculation was performed using G*Power software (version 3.1.9.7) (31). It was set to a within factors repeated-measures analysis of variance (ANOVA) with a desired power (1- ß) of 0.80 and assuming an alpha (α) level of 0.05. As a result, a specified sample size of 12 participants was deemed satisfactory to detect a large effect size ($\eta_p^2 = 0.14$), which is representative of changes in the volume load lifted attributed to palm cooling in previously published research(17, 18).

Twelve healthy, male volunteers volunteered for this study, however due to Covid-19 related issues, one participant dropped out prior to the beginning of the study. Therefore, 11 (age, 23 ± 5 years; mass, 86.8 ± 18.4 kg; height, 1.79 ± 0.08 m) volunteers completed the study. Participants were recruited from the local university campus and gyms using posters, e-mails and word of mouth. To be eligible for the study, individuals needed to be between 18–39 years of age and currently participating in upper body resistance training at least once per week, with a minimum of one year of upper body resistance training experience. The resistance training experience for the study sample was 5 ± 2 years. Inclusion criteria included not having any musculoskeletal or neurological disorders, being free from injury and not supplementing with any ergogenic aids either 3 months prior to or during the study.

Following a pre-screening physical activity questionnaire to ensure eligibility, participants were provided with an information sheet, outlining the full experimental procedure and risks involved. All participants gave their written informed consent to participate. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ulster University School of Sport Ethics Committee.

Experimental design:

The experimental design was a randomized, double blind, controlled, crossover study, which was largely replicative of the designs used in previous palm and sole cooling studies(3, 17, 18). This included four experimental visits to the laboratory, each separated by four days. The first laboratory visit included establishing each participant's 1RM and familiarizing them with the experimental exercise protocols. Prior to 1RM testing, no participants had participated in upper body exercise within at least 48 hours, nor had they consumed any caffeine, stimulants or other ergogenic aids with the potential to acutely modulate resistance exercise performance within the previous 24 hours.

Procedures

One-Repetition Maximum (1RM) Testing

Before performing an attempt on their 1RM, participants were asked to estimate their 1RM based on their most recent training performance. From this estimation participants performed a standardized warm-up of six repetitions at 50% 1RM, four repetitions at 80% 1RM, one repetition at 85% 1RM and one repetition at 90% 1RM with 60-seconds between sets. Following 3 mins of passive recovery participants then proceeded to attempt their 1RM. They were asked to use their preferred barbell grip width that they used to habitually perform the bench press during their own training history, which was assessed and maintained during each subsequent 1RM attempt. The load which was added to the bar was estimated and agreed upon by the primary investigator and participant. Each participant was allowed 3 mins recovery between each 1RM attempt. All participants achieved their 1RM within ≤4 lifts. A 1RM was defined as the maximal amount of weight lifted during a complete, full range-of-motion repetition of the bench press exercise. Full range-of-motion for the 1RM and experimental trials was defined as lowering the bar to the xiphoid process and raising the bar until full extension of the elbow had occurred. Safety bars and two spotters were employed during the 1RM attempts with full verbal encouragement provided during each attempt. Once the 1RM had been established, participants were allowed five minutes of passive recovery, before completing one set of supine bench press exercises to exhaustion at 80% 1RM for familiarization. Each participant completed three experimental conditions 1) palm-cooling at 10^{o}C (TEN), 2) palm-cooling at 15^{o}C (FTN), and a thermoneutral control condition (CON) in a randomized order, recorded and managed by a researcher independent to the study. The experimental conditions of each participant's visit were not revealed to the investigators or participants until post analysis. During each of the three experimental trial days, participants performed four sets of bench press at 80% 1RM to volitional exhaustion, separated by 3 mins of passive recovery whilst the palm was exposed to one of the experimental conditions. During each of the four visits, participants performed the exercise protocol at the same time day to minimise any potential effects of circadian rhythm on muscle performance. Three days existed between the 1RM/ familiarization session and the first experimental trial. All sessions were carried out under identical laboratory conditions (19^{o}C, 65% Relative humidity, 1008 hPa) and Figure 1 provides a schematic diagram of the experimental set-up.

INSERT FIGURE 1 HERE

Experimental Exercise Protocol

Prior to commencing the experimental exercise protocol on any of the three trial days, participants completed a standardized warm-up of five repetitions at 50% 1RM, four repetitions at 70% 1RM and one repetition at 80% 1RM. Participants rested for 3 mins before performing an MVIC for EMG normalization (see Electromyography section). Upon completing the MVIC, participants rested for a further 5 mins and then performed four sets of as many repetitions as possible until volitional exhaustion at 80% 1RM interspersed with three minutes of recovery. Verbal encouragement was provided at all times by the lead investigator. A repetition was not counted if it violated the previous definition of a successful repetition. Repetitions were performed with a 2 s eccentric, 2 s concentric phase tempo monitored via a metronome, and the number of successful repetitions were recorded. Exercise was terminated and termed volitional exhaustion when a full repetition could not be completed, that is the lowering and raising of the bar through the full range-of-motion as previously outlined.

Experimental Conditions

Palm cooling and the thermoneutral condition were induced by the Core TX Thermal Exchange palm cooling device (CET Ltd, Dromore, Northern Ireland). During each of the 3-min recovery periods between resistance exercise sets, participants placed their palm over a large circular opening in the roof of the device, forming a water-tight seal. The cooling device then expelled a single, continual vertical jet of water up to the palm of the hand from the basin below. Palm cooling or thermoneutral water was applied to the palm surface for 60s during the inter-set rest periods as per manufacturer’s recommendation. During the recovery, palm cooling or thermoneutral water was applied from the 30th to the 90th second of the 3 min period. This 30 s time delay from the cessation of exercise to cooling initiation was due to the time taken needed to transition from the bench press to the cooling device and for some of the immediate post-exercise physiological measures to take place. The water temperature was maintained at 10°C (TEN), 15°C (FTN) and 28°C (CON) for the two experimental and control trials respectively. Palm temperature was assessed via an infrared skin thermometer (Berrcom JXB-178, Nansha, GuangZhou, China) at 3 cm from the skin surface after approximately 1 s. Palm temperatures were initially assessed during the familiarization session. Participant's palm temperatures were taken three times before any exercise had commenced 10 mins after reporting to the laboratory. The mean of each participant's palm temperature was then used to calculate the thermoneutral condition rather than a pre-planned thermoneutral condition as used in other studies. The mean thermoneutral palm temperature was 28.0 ± 2.8°C. The reliability of the device was deemed excellent with a mean coefficient of variation of 2.9% ± 0.8°C. During each of the experimental trials, palm temperature was recorded immediately post exercise (within ~6-10 s), immediately post condition cooling/thermoneutral exposure following drying of the palm, and at the end of the recovery period.

Electromypography (EMG):

Surface EMG signals were acquired at a sample rate of 2,000 Hz using a Delsys Wireless Trigno system (Delsys Inc., Boston, MA, USA) connected to a digital data acquisition unit (PowerLab 16/35, AD Instruments, Oxford, UK). One bipolar Trigno sensor was used per muscle site, with each sensor containing Ag/AgCl electrodes with a 10 mm inter-electrode distance, with a dual on-board stabilising reference. The system filtered the EMG data with a 4th – order zero-lag Butterworth filter from 20-450 Hz. Raw EMGs were then processed as root mean square (RMS – 100 ms window) over the entire duration of each muscle contraction using LabChart v8 software (AD Instruments, Oxford, UK). Both peak and mean RMS EMG were obtained from each contraction. As it is inappropriate to compare processed EMGs across multiple days/conditions, the mean or peak RMS EMG from each bench press was normalised to by dividing it by the mean or peak RMS EMG, respectively, (200 ms in total, 100 ms either side of the single instantaneous peak data point) elicited during the MVIC recorded on the same experimental day. This was also the method employed to identify peak EMG activity for each contraction during bench press exercise. RMS EMG during the bench press exercise was normalized to the pre-exercise MVIC RMS EMG of that particular experimental session. A spectral analysis was also simultaneously performed, with a Fast-Fourier transformation applied to the raw EMG signal to provide the power spectral density, from which the mean (MF) and median (MDF) frequency of each contraction were assessed. As with EMG amplitude, it is not recommended to compare spectral frequency data across days, nor is it recommended to normalise to a reference task. Therefore, the relative changes in MF and MDF from set 1 (within-day control prior to any cooling/ thermoneutral exposure) to set 4 was calculated, using the mean of all contractions for each condition.

Electromyograms were recorded from the sternal head of the pectoralis major, anterior deltoid (AT) and long head of the triceps brachii (Tri). For the AT and Tri, electrodes were placed along the longitudinal axis of the muscles, over the centre of the muscle belly according to the SENIAM guidelines (13). For the pectorals major, the investigator palpated the participant’s upper chest to find both the most lateral edge of the clavicle at the acromion and sternoclavicular joint. An anthropometrical segmometer was used to measure the length of the clavicle with a vertical line drawn downward through the middle of the pectoral muscle from 50% of the clavicular length. The segmometer was again used to identify the total length of the sternum, with a horizontal line drawn from 50% of sternum length to the midbelly of the muscle. Where the horizontal and vertical lines intersected, approximating the 3rd sternal head of the pectorals, was used as the electrode location. Each electrode's bipolar arrangement was positioned perpendicular to the muscle's line of pull. To ensure that electrodes were located in the same place for each condition, the locations described above were marked with a 2 cm crosshair using an anatomical pen, which remained clearly visible for the duration of the study. Regardless, each cross hair was checked for accuracy during each visit as a precaution. Before electrodes were attached, all locations were prepared by shaving, abrading using a commercially available dermal scrub (St. Ives, UniLever, Wirral, England) and cleansed with an alcohol swab to reduce skin impedance. Each electrode was secured using a combination of the system manufacturer's own specific electrode double-sided adhesive tape, and further fixation with additional adhesive tape. Due to poor signal quality, one participant's EMG data was removed from analysis.

Maximal Voluntary Isometric Contraction (MVIC)

For EMG signal normalisation, following 3 minutes of passive rest post warm-up, the barbell was placed on safety bars set at the level of the bottom of the participants' range-of-motion (i.e. 2 cm above the xiphoid process). The participants gripped the bar as previously, and upon the investigator's instruction, produced 2 x 4 s maximal voluntary isometric contractions (MVICs) against the static barbell separated by two minutes recovery. The highest EMG amplitude of the two contractions was chosen to normalise the bench press EMGs to on each day.

Bench Press Mean Power

Mean Power was assessed via a commercially available linear position transducer (LPT) consisting of a floor unit, made up of a spring-powered retractable cable that is wound on a cylindrical spool coupled to the shaft of an optical encoder (GYM Aware Power Tool, Kinetic Performance Technologies, Canberra, Australia). The floor unit was placed perpendicular to the left collar of the barbell and the other end of the cable was vertically attached to the barbell using a velcro strap. Vertical displacement of the barbell was sampled at 50 Hz via the rotational movement of the spool, and data were time-stamped at 20 ms time points to obtain a displacement-time curve for each repetition. Velocity of the barbell was determined by dividing its displacement by time, and further divided by time to obtain acceleration. Mean force was calculated as the product of the system mass and the acceleration of the barbell, where system mass was the barbell mass plus the body mass of the participant. Mean Power was then calculated as the product of mean force × velocity of the barbell. Data were transmitted through Bluetooth to a tablet (iPad; Model A1474, Apple, Inc., Cupertino, CA, USA) using the GymAware v2.1.1 app. The participant's body mass and the barbell load used were entered into the GymAware app prior to exercise at each experimental trial(22).

Statistical Analysis

All statistical analysis was performed using JASP software (version 0.14.1; JASP, Amsterdam, The Netherlands). Prior to parametric tests, the normality of distributions was determined by the Shapiro-Wilk test. A two-way (temperature condition [CON, TEN and FTN] x measurement time point) within repeated-measures ANOVA evaluated the temperature effects and time effects. Where Mauchly's assumptions of sphericity were violated, Greenhouse-Geisser corrections were used. A one-way (temperature condition [CON, TEN and FTN]) repeated-measures ANOVA was used to evaluate the temperature effects on exercise volume. Where applicable, *post hoc* analysis was performed using Holm's corrections. Partial eta squared (η_p^2) statistics were calculated as a measure of effect size, where 0.01 = small; 0.06 = medium; and 0.14 = a large effect. The α-level for statistical significance was set at $p < 0.05$. Data were presented as mean ± SD, unless otherwise stated. For dependent variable reliability, a two-way, single measure, mixed model with 95% Confidence Intervals (CI) Intraclass Correlation Coefficient (ICC) (interpreted based on the lower bound CI as [<0.50] poor,[0.5–0.74] moderate, [0.75–0.90] good, and [>0.90] excellent were calculated to assess reliability of each of the dependent variables(5).

RESULTS:

Dependent Variable Reliability

Exercise Performance; Within day and between day bench press performance ICC were 0.87 (lower bound 0.96) and 0.62 (lower bound 0.88) respectively.

Palm Temperature; Within and between day palm temperature ICC were 0.98 (lower bound 0.93) and 0.93 (lower bound 0.96).

EMG Amplitudes; Within day reliability of the pectorals, anterior deltoid and triceps brachii were 0.96 (lower bound 0.94), 0.93 (lower bound 0.89) and 0.90 (lower bound 0.88) respectively for mean EMG amplitude. Between day reliability of the pectorals, anterior deltoid and triceps brachii were 0.92 (lower bound 0.87), 0.88 (lower bound 0.89) and 0.87 (lower bound 0.83) respectively for mean EMG amplitude. Within day reliability of the pectorals, anterior deltoid and triceps brachii were 0.98 (lower bound 0.97), 0.96 (lower bound 0.97) and 0.92 (lower bound 0.93) respectively for peak EMG amplitude. Between day reliability of the pectorals, anterior deltoid and triceps brachii were 0.92 (lower bound 0.91), 0.90 (lower bound 0.93) and 0.88 (lower bound 0.86) respectively for peak EMG amplitude.

Spectral Data; Within day reliability of the pectorals, anterior deltoid and triceps brachii were 0.97 (lower bound 0.95), 0.95 (lower bound 0.98) and 0.96 (lower bound 0.98) respectively for MF. Between day reliability of the pectorals, anterior deltoid and triceps brachii were 0.96 (lower bound 0.93), 0.94 (lower bound 0.88) and 0.95 (lower bound 0.94) respectively for MF. Within day reliability of the pectorals, anterior deltoid and triceps brachii were 0.98 (lower bound 0.99), 0.96 (lower bound 0.95) and 0.91 (lower bound 0.94) respectively for MDF. Between day reliability of the pectorals, anterior deltoid and triceps brachii were 0.93 (lower bound 0.94), 0.89 (lower bound 0.91) and 0.92 (lower bound 0.91) respectively for MDF.

Therefore, reliability of all dependent variables was deemed good to excellent.

The results of the Shapiro-Wilk tests indicated that all dependent variables were not statistically different from normally distributed (all $p > 0.05$).

Exercise Performance

The two-way ANOVA revealed a significant main effect of time ($F_{3,30} = 110.5$, $p < 0.001$, $\eta_p^2 = 0.92$), with the number of repetitions progressively decreasing from the first set to the last (Figure 2). While the main effect for temperature ($F_{2,20} = 0.2$, $p = 0.716$, $\eta_p^2 = 0.02$) and the time x temperature interaction revealed no significant effects ($F_{6,60} = 0.74$, $p = 0.618$, $\eta_p^2 = 0.07$). Post-hoc analysis revealed that at each time point, the number of repetitions completed was significantly different from all other time points (all values $p < 0.05$).

There was also a significant main effect of time ($F_{3,30} = 11.3$, $p < 0.001$, $\eta_p^2 = 0.53$), with mean power progressively decreasing from the first set to the last (Figure 3). While the main effect for temperature ($F_{2,20} = 0.89$, $p = 0.428$, $\eta_p^2 = 0.08$) and the time x temperature interaction revealed no significant effects ($F_{6,30} = 1.08$, $p = 0.359$, $\eta_p^2 = 0.10$), post-hoc analysis revealed that at each time point, power was significantly lower than during Set 1 ($p < 0.05$).

INSERT FIGURE 2 HERE

INSERT FIGURE 3 HERE

Palm Temperature

Palm temperature showed main effects of time ($F_{11,110} = 46.5$, $p < 0.001$, $\eta_p^2 = 0.82$), temperature ($F_{2,20} = 154.0$, $p < 0.001$, $\eta_p^2 = 0.94$) and the time x temperature interactions ($F_{22,220} = 41.0$, $p < 0.001$, $\eta_p^2 = 0.80$). Post-hoc analysis revealed that at each time point, palm temperature during CON was significantly higher than the other two conditions, with the exception of post-exercise 1, 2 and post-exercise 3 for FTN condition. In addition, palm temperature during the TEN was significantly lower than FTN at post-cooling 1,2, 3 and 4 ($p < 0.05$, Figure 4).

INSERT FIGURE 4 HERE

Electromyography

EMG Amplitude; EMG data are presented in Table 1. There was no significant main effect of time ($F_{3,27} = 1.2$, $p = 0.34$, $\eta_p^2 = 0.12$), temperature ($F_{2,18} = 1.0$, $p = 0.381$, $\eta_p^2 = 0.10$) or time x temperature interaction ($F_{6,54} = 2.3$, $p = 0.09$, $\eta_p^2 = 0.21$) for mean pectoralis EMG amplitude. There was no significant main effect of time ($F_{3,27} = 3.9$, $p = 0.02$, $\eta_p^2 = 0.30$), temperature ($F_{2,18} = 1.0$, $p = 0.373$, $\eta_p^2 = 0.10$) or time x temperature interaction ($F_{6,54} = 0.60$, $p = 0.733$, $\eta_p^2 = 0.06$) for mean deltoid EMG amplitude. There was no significant main effect of time ($F_{3,27} = 1.3$, $p = 0.285$, $\eta_p^2 = 0.13$), temperature ($F_{2,18} = 0.2$, $p = 0.808$, $\eta_p^2 = 0.02$) or time x temperature interaction ($F_{6,54} = 1.6$, $p = 0.172$, $\eta_p^2 = 0.15$) for triceps mean EMG amplitude. Peak EMG amplitude for deltoids, pectorals and triceps showed a main effect of time ($F_{3,27} = 20.5$, $p < 0.001$, $\eta_p^2 = 0.70$; $F_{3,27} = 11.7$, $p < 0.001$, $\eta_p^2 = 0.56$; $F_{3,27} = 51.4$, $p < 0.001$, $\eta_p^2 = 0.85$

respectively). While the main effect for condition i.e. temperature ($F_{2,18} = 3.7$, $p = 0.076$, $\eta_p^2 = 0.29$; $F_{2,18} = 1.4$, $p < 0.265$, $\eta_p^2 = 0.14$; $F_{2,18} = 0.3$, $p < 0.727$, $\eta_p^2 = 0.04$) and the time x temperature interaction revealed no significant effects ($F_{6,54} = 0.8$, $p = 0.585$, $\eta_p^2 = 0.08$; $F_{6,54} = 1.7$, $p = 0.129$, $\eta_p^2 = 0.16$; $F_{6,54} = 0.9$, $p = 0.497$, $\eta_p^2 = 0.09$) for peak deltoids, pectorals and triceps EMG amplitude, respectively. Post-hoc analysis revealed that peak EMG amplitude for deltoids, pectorals and triceps in Set 4 was significantly higher than the other time points ($p < 0.01$). In addition, peak EMG amplitude for triceps in Set 3 was significantly different than the other time points ($p < 0.01$).

Spectral Analysis; The relative change in MF for deltoids (TEN -6 ± 6%, FTN -3 ± 6%, CON -2 ± 5%), pectorals (TEN -6 ± 6%, FTN -3 ± 7%, CON -3 ± 6%) and triceps (TEN -6 ± 10%, FTN -4 ± 4%, CON -1 ± 11%) revealed no significant differences between any of the experimental conditions ($F_{2,18} = 1.18$, $p = 0.331$, $\eta_p^2 = 0.12$; $F_{2,18} = 0.74$, $p = 0.493$, $\eta_p^2 = 0.08$; $F_{2,18} = 1.84$, $p = 0.187$, $\eta_p^2 = 0.17$ respectively). The relative change in MDF for deltoids (TEN -3 ± 5%, FTN -2 ± 4%, CON -1 ± 3%), pectorals (TEN -1 ± 2%, FTN -3 ± 4%, CON -1 ± 4%) and triceps (TEN -3 ± 3%, FTN -3 ± 3%, CON -2 ± 4%) revealed no significant differences between the temperature conditions ($F_{2,18} = 0.49$, $p = 0.624$, $\eta_p^2 = 0.05$; $F_{2,18} = 0.62$, $p = 0.552$, $\eta_p^2 = 0.06$; $F_{2,18} = 0.46$, $p = 0.638$, $\eta_p^2 = 0.05$ respectively).

INSERT TABLE 1 HERE

DISCUSSION:

The aim of the current study was to investigate the acute effects of palm cooling with application of appropriate EMG methodologies, specifically comparing two cooling conditions to a thermoneutral condition (CON) on exercise performance and muscle activation. The main findings of the current study are that there appears to be no impact of palm cooling on the RMS EMG amplitude or power density spectrum of the agonist and synergist muscles of the bench press, and neither of the cooling conditions were able to attenuate effects of fatigue during acute resistance exercise performance versus a control condition.

In two separate studies, but using an identical counter-balanced study design, Kwon et al. (17, 18) demonstrated that in both healthy, resistance-trained, young males and females, inter-set palm cooling for 2.5mins (within a 3min recovery period) at 10^{o}C during 4 sets of bench press to exhaustion, enhanced the amount of repetitions and total exercise volume completed compared to a thermoneutral control condition. Those authors also found that the RMS EMG was higher in the cooling condition compared to control in some of the bench press synergistic muscles (anterior deltoid and triceps brachii). In the current study, we also employed 4 sets to exhaustion, interspersed with 3 mins recovery time using cooling at 10^{o}C as well as 15^{o}C, yet we did not find the same effect on the number of repetitions or RMS EMG amplitude. The current study aimed to address some of the limitations present in the EMG methodologies employed in the aforementioned studies by Kwon et al. (17, 18) and Cai et al.(3), namely 1) normalizing the RMS EMG to an appropriate reference task (MVIC), 2) using the within session relative change as opposed to a maximal reference task for spectral data normalization, and 3) taking the mean of every repetition's EMG amplitude per set. The normalization of EMG to a maximal reference task that is the same as the task under investigation (i.e. a 1RM bench press) is not recommended because 1) this does not necessarily produce a maximal activation level in any of the muscles investigated because during a dynamic assessment, the weight of the bar has to be overcome by muscle force. Thus, there is no indication that maximal activation has been achieved, nor would it be possible to identify in which muscles it had been achieved in (e.g. prime mover, synergists). 2) Different individuals may use different muscle control strategies to produce the same movement(12). On inspection of Cai et al. (3), the RMS EMG amplitude produced during the sets when normalised to 1RM leg press ranged from 53-75% in the cooling condition from first to fourth set, with similar values in the control condition. With a pyramidal loading scheme employed at 85-90% 1RM, at such relatively high force levels, the normalised EMG amplitudes do not seem as high as one would expect, especially under repeated fatiguing contractions where EMG amplitudes are of even greater magnitude(6, 16). When normalised to an MVIC, we found no differences in RMS EMG in any of the measured muscles in the current study. Furthermore, in the methods used in previous investigations, Kwon et al.(17, 18) calculated the RMS EMG percentage difference between the first repetition of the first set and the final repetition of the final set as evidence of neural function. As outlined in the introduction the potential for error in assessing only two individual electromyograms per condition, per person, separated by at least 3 days, is large. In the current study we analysed the RMS EMG amplitude of every contraction from each set, from each of the conditions, which resulted in excess of 20 electromyograms per person per condition. We then used the mean RMS EMG amplitude from all repetitions per set for the within and between comparisons, which is likely to reduce the susceptibility to error considerably. Our current EMG results agree with those of Batra et al.(1) who induced sole cooling at ~10^{o}C during four sets of resistance training to fatigue at 90% of 10RM. Average and peak EMG amplitudes of the Rectus Femoris and Vastus Medialis Obliquus were not different between the sole cooling and control conditions. Finally, whilst performing their spectral analysis, Kwon et al.(17, 18) normalised the MF and MDF data to the 1RM task performance, and reported significantly higher MF and MDF in muscles under the cooling condition compared to control. In a spectral analysis, changes in the shape of the power density function of the EMG are what is important, where the power density may shift to lower frequencies under fatigue. Therefore the amplitude of the EMG signal is not important and thus normalisation to a maximal reference task is not recommended(12, 26). Currently, the authors used the common approach of calculating the relative change in spectral data between set 1 (i.e. the within session control) to the final set. We found no differences in any of the spectral data between conditions in any of the muscles investigated. The primary proposed mechanism for the ergogenic effect of palm or sole cooling (i.e. cooling distal to the agonist muscle) is the effects of cooling on the nervous system via potential modulation of afferent feedback pathways. Briefly, several sources of sensory stimuli such as cooling, heating, vibration, rubbing or electrical stimulation can alter or block the transmission of afferent signals via the central nervous system (CNS) to the brain that may eventually be perceived as ‘pain’ according to the ‘Gate Control Theory’(21). If such ‘painful’ stimuli aren’t detected, exercise would be allowed to continue, hence more repetitions under fatiguing conditions may be completed. Palmieri-Smith et al.(24) supports a neural mechanism for the ergogenic effects of cooling by demonstrating an increased H-reflex, M-Wave, H:M ratio and serum norepinephrine levels following application of ice packs to the ankles in young males and females. However, the effect on neurotransmitters and motoneuron excitability was not observed until 10 minutes post-cooling with no effects on any of the measures immediately post-cooling. Therefore, based on the current findings, further investigations in identifying the potential ergogenic mechanism of palm/sole cooling (if one exists), is yet to be definitively demonstrated. Employing technologies that permit EMG signal decomposition (such as HD-EMG) should also be used to provide more mechanistic insight than use of relatively large surface electrodes.

In terms of exercise performance, the current study’s findings agree with those of Batra et al.(1), who detected no differences in repetition number or exercise volume in the cooling condition versus control. Esteves et al. (8) investigated the effects of four different cooling strategies on acute exercise performance in 9 healthy, young males. Participants completed four sets of bicep curls at 80% 1RM to exhaustion, with a 1 min inter-set rest period. Cooling was achieved with ice pack application to either the palm, neck, local (over muscle) or face (tunnel temperature cooling) and were all compared to a control condition. Neither number of repetitions or RPE were improved via any of the cooling methods compared to control. Apart from the palm-cooling studies of Kwon et al.(17, 18), Cai et al.(3) reported improved exercise performance (i.e. number of repetitions) using sole-cooling during leg press exercise to exhaustion using an almost identical study design to that of Kwon et al.(17, 18) and the current study. What is most interesting about Cai et al's.(3) study is that the number of repetitions performed in sets 2 and 3 actually increased compared to the first set, with the fourth set not statistically different from the first set. Therefore, in a protocol to volitional neuromuscular failure with only 3 minutes rest between, exercise performance not only did not decline after four sets, but actually improved in the cooling condition. These findings are not only not commensurate with all other cooling studies to fatigue, where all studies showed a systematic decrement in performance over the exercise protocol, but do not agree with general principles of neuromuscular function and physiological recovery following fatigue(7). In fact, it has recently been shown that as much as 8 mins of intra-set recovery may be required to sustain the number of repetitions completed between set 1 and set 4 during high-intensity bench press at 85% 1RM(14). This therefore raises questions over the deployment of the experimental design of the Cai et al.(3), specifically whether their participants truly carried out the exercise to failure, particularly in set 1, or despite familiarisation and counter-balancing condition order, whether there was also a learning effect.

One of the key differences between previous palm cooling studies and the current study was the cooling method and duration of cooling application associated with it. Kwon et al.(17, 18) used a bespoke thermal exchange glove in which the palm rests on a metal plate with cooled water circulated underneath, inducing cooling via heat conduction from the palm. The current authors used a thermal exchange device that continually washes cooled water directly over the palm surface, thus inducing cooling using both conduction and convection. Heat loss from a combination of both conduction and convection is more rapid and of greater magnitude than conduction alone at the same temperature(15). As such, we employed cooling for a duration of only 60 seconds compared to 150 seconds by Kwon and co-workers. This was due to the manufacturer’s recommendations as longer duration cooling using this method may induce severe vasoconstriction in the hand of participants. Following cooling at 10^{o}C, post cooling palm temperatures in the current study fell from ~22^{o}C in set 1, to ~15.5^{o}C post cooling at set 4. However, by the time the recovery period concluded, palm temperatures had risen back to ~22^{o}C. Kwon et al.(17) reported that palm temperatures following 150 seconds of cooling were ~22^{o}C in their study of young, resistance trained males, which was similar to this study. Both studies from Kwon and colleagues, as well as the current study, all employed resistance trained individuals with on average ≥5 years experience. However, a further strength to the current study design compared to previous studies is that both participants and investigators were blinded to the experimental and control conditions until post analysis.

Previous investigations have incorporated various intermittent cooling strategies during the rest periods of high intensity resistance exercise in order to augment acute performance. These strategies have involved application of cooling directly on the agonist muscle undergoing exercise(8, 10, 30), distal to the agonist muscle undergoing exercise but on the same limb(1, 3, 8, 11, 17, 18) (i.e. palm cooling for upper body musculature), or distal to the agonist muscle undergoing exercise on a different limb (i.e. palm cooling during lower body exercise)(4). Taken together, these studies have reported either a positive effect of cooling on acute resistance exercise performance compared to a control condition(3, 4, 10, 17, 18, 30) or no effect on performance compared to a control condition(1, 8). Aside from the chosen method of cooling application, these studies also investigated different agonists (such as pectorals, latissimus dorsi, biceps brachii, quadriceps femoris), used different loading intensities (70-90% 1RM), different inter-set recovery periods (1-3 mins) and different populations with varying degrees of resistance training experience (6 months to >5 years). The cooling techniques also differ markedly between studies, with some using ice packs, others immersion of the distal limb in water, and some fitted with a cooling glove. Cooling temperatures ranged from 10-15°C or were not specified (i.e. application of an ice bag). As such it is difficult to assess accurately the exact nature of cooling in some of the studies, due to the lack of control over cooling stimulus e.g. ice melting and temperature fluctuation. This heterogeneity between studies, and with a limited amount of studies being performed, makes direct comparisons of results between them difficult.

PRACTICAL APPLICATIONS:

The current study demonstrated that palm cooling did not enhance acute bench press performance or neural responses compared to a thermoneutral condition. Our findings cast doubt on previous assertions that a neural mechanism is responsible for the ergogenic effects of palm/sole cooling distal to the agonist muscle, and this could be attributed to more appropriate EMG methodologies employed in our study. Therefore, for practitioners who are seeking to enhance acute high-intensity resistance exercise performance in resistance-trained populations, cooling does not provide any further ergogenic benefit.

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Figure Captions:

Figure 1: Schematic diagram of study design and protocols.

Figure 2: Number of repetitions completed in TEN (black circles), FTN (white squares) and CON (white circles) groups in each set. * Significantly different ($p<0.05$) to all other sets.

Figure 3: Mean Power in TEN (black circles), FTN (white squares) and CON (white circles) groups in each set. * Significantly different ($p<0.05$) to set 1.

Figure 4. Palm temperature during each set of the four sets. Temperatures were taken post-exercise (PE), post-cooling (PC) and at the end of each recovery period (PR). * Significant difference ($p<0.05$) between CON and the other two conditions. $ Significant difference ($p<0.05$) between CON and TEN degree condition. † significant difference ($p<0.05$) between TEN and FTN condition.