Skin Application of Menthol Enhances Maximal Isometric Lifting Performance

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ABSTRACT

Topical application of menthol to the skin improves perception (i.e., makes subjects feel cooler) and changes sub-maximal neuromuscular recruitment facilitating force generation. We explored the effect of menthol (0.2% concentration; sprayed on the legs), on perception and maximal, dynamic (DLT) and isometric (IMLT) [weight] lifting tasks. Nine resistance trained males (mean ± SD: 24 ± 5 years; 75.7 ± 8.8 kg; 174 ± 10 cm; 5 repetition maximum deadlift [5RM] 132.3 ± 28.5 kg) were tested using a repeated measures design; we hypothesized performance would improve. Prior to completing the DLT (i.e., deadlift performance 75% 1RM) and a mid-thigh pull dynamometer IMLT, subjects were sprayed with (~125 mL) of Menthol or Control-Spray. Performance, electromyography (root mean squared rmsEMG; rectus femoris[RF], biceps femoris[BF], medial gastrocnemius[MG]), perceptions (Leg thermal sensation[TS_{legs}] and comfort[TC_{legs}], perceived exertion [RPE] and readiness to train), heart rate and skin temperature were measured. Data were compared using ANOVA (effect size ηp^2) and t-test to 0.05 alpha level supported by Bayesian analysis. DLT performance was unchanged although BF rmsEMG was higher (i.e., greater muscle activation in final [10^{th}] repetition). IMLT force production was higher in the Menthol-Spray (148 ± 30 kgf) condition (Control-Spray 140 ± 30 kgf; $p = .035$, $\eta p^2 = .444$) with corresponding higher rmsEMG (BF 3.8 ± 1.46 vs. Control-Spray 2.9 ± 0.34 v; $p = .049$, $\eta p^2 = .403$). TS_{legs} was lower after Menthol-Spray prior to IMLT; subjects felt *slightly cool*. Menthol-Spray enhances isometric weightlifting performance with corresponding changes in neuromuscular activity; partially supporting our hypothesis.

INTRODUCTION

Resistance training is a common practice for team and individual sport athletes with the aim being to transfer the attributes enhanced by effective strength and conditioning to improve athletic performance (3). Therefore, optimized performance of dynamic and isometric resistance exercise is critical to evoke the required adaptations in muscular hypertrophy, maximal strength, rate of force development (RFD), and power output (34). Muscle fatigue, defined as the inability of a muscle to generate force or power, is the primary limiting factor in effective performance of these activities at the maximal levels (3,26).

Peripheral (i.e., beyond the motor end plate) dynamic maximal resistance exercise performance is limited by the permitted rate of excitation-contraction coupling and cross-bridge cycling, with contraction velocity dependent on the extent of active skeletal muscle loading vs unloading (10). In contrast, isometric resistance exercise focused on maximal explosive power is limited by the rate of muscle fiber recruitment dictated by the time course of increased intracellular calcium (Ca^{2+}) and the sustained ability of the formed cross-bridges to maintain the resultant force (9). For isometric contractions, the characteristic pattern of force development depends on muscle fiber type composition and muscle temperature (12). Collectively, any intervention that inhibits the limiting mechanisms to dynamic and isometric fatigue, including those that are centrally limiting (27), has the potential to enhance power, strength, or both and subsequently enhance the training transfer to athletic performance.

Prior to evoking maximal dynamic and isometric contractions, it is common to undertake a generic and then specific warm-up. In addition to reducing injury risk, inducing beneficial cardiovascular adjustment and perceived psychological readiness (31), warming up also optimizes the contraction characteristics of skeletal muscle (1,12). For example, increasing

muscle temperature to 39.3°C results in an 11% increase in dynamic maximal peak force and power (33). High muscle temperatures are associated with a 10% increase in peak power per degree Celsius but also a higher fatigue rate (33). Cooling muscle temperature to 31.9°C results in a 12 and 21% reduction in dynamic maximal peak force and power, respectively. The performance of isometric activities with added heat, also improves contraction characteristics, i.e., improving RFD, decreasing relaxation rate and increasing the number of muscle fibres recruited for a given contraction (16). Collectively, the neuromuscular benefits of an effective warm-up are beyond dispute.

The surface thermal characteristics of active muscles have also proved to be important in determining the electromyographic (EMG) muscle response, the RFD, and motor unit recruitment in sub-maximal and maximal isometric contractions (22,35,43). For example, *decreasing* skin temperature from a "normal" physiological range of 31 to 25°C (i.e., typical ambient air temperature for a gym environment) independent of muscle temperature, *increases* the number of motor-units recruited during a 30% voluntary sub-maximal contraction (43). Moreover, transient skin cooling increases RFD with corresponding increases in EMG activity (i.e., greater muscle excitation) during maximal isometric knee extension (35). During dynamic contractions, cooling between resistance exercises sets (i.e., palmar cooling to 22°C between bench press resistance exercise efforts at 85% of one repetition maximum; RM) was shown to increase total work done by 30% albeit in conjunction with negative pressure; the evoked facilitatory mechanism was speculated to be related to pain relief (22). Thereafter the relationship between skin temperature and force output may also be influenced by deep body temperature with improved central nervous system neuromuscular recruitment associated with raised temperatures (13). Yet the sensation of improved perception when the skin is cooled at high deep body (and muscle) temperatures has the potential to improve performance of

dynamic fatiguing contractions (38). To date, an ecologically valid intervention and protocol that harnesses the benefits of warm-up to muscular performance combined with the neuromuscular and perceptual enhancements induced by skin cooling has yet to be identified probably due to practical limitations in implementing this approach.

For example, menthol, from peppermint and corn mint, is extracted from plants of the *Mentha* genus and is a naturally occurring cyclic terpene alcohol (28,29). Of the eight recognized forms the (-)isomer is responsible for menthol's fresh aroma, taste and cooling sensation when applied to mucous membranes or the skin (28,29). Its effects being inversely proportional to the thickness of the membrane to which it is applied (40). Menthol elicits these sensations by primarily stimulating the membrane bound ion channel transient receptor potential melastatin 8 (TRPM-8), chemically mimicking a temperature change within the range of 8 to 28ºC (29). Importantly, menthol stimulation has the potential to reflect thermal change in temperature, in the absence of true change thereby evoking a cooling sensation by biochemical means (4,5). From a practical perspective, low concentrations of L Menthol sprayed to the skin (0.2% menthol-spray to the torso) were shown to evoke these cooling sensations, in contrast to a control-spray, for up to 25-minutes (20). Moreover, menthol application (5% menthol gel applied to the quadriceps) increased EMG activation during low load (35% of maximum) isometric contractions; inferring the potential to improve fatigue rate and maximal level performance (39). Menthol application (0.2% menthol spray to the torso) improved dynamic endurance performance, as evidenced by a greater time to exhaustion during exercise in the heat with a concomitant improvement in thermal perception (i.e., feeling cooler) (5).

Considering such observations, menthol application to the skin after an effective warm-up may maximize neuromuscular benefits in force development triggered by a transient reduction in skin temperature, without compromising the warm-up induced increase in internal temperature.

Moreover, menthol application also has the potential to avoid evoking inhibitory neuromuscular reflexes associated with the combination of cool muscle and skin temperatures (25). On this basis, the application of menthol combined with an effective warm-up, appeared a plausible and practical intervention to improve the performance of maximal isometric resistance exercises and possibly, dynamic activity. Accordingly, this study sought to examine if a low concentration of menthol, applied by spray to the legs prior to weightlifting, could improve performance, perception, and muscle activation in a dynamic and isometric lifting task; we hypothesized it would. We also sought to measure mechanistic surrogates, such as muscle EMG activity and thermal sensation, that could inform whether any facilitation in performance could be attributed solely to peripheral neuromuscular alterations or a combination of central and peripheral mechanisms (i.e., sensory feedback).

METHODS

Experimental Approach to the Problem. To establish the effects of L-Menthol on perception and weight-lifting performance, subjects undertook two main experimental conditions with a prior baseline laboratory visit to establish maximal weight-lifting capability (see Figure 1). For each main condition subjects completed maximal dynamic and static (isometric) weight-lifting tasks (i.e, DLT & IMLT) with prior spraying with Menthol-Spray or a Control-Spray. A within-subject repeated measures design was utilized with test conditions randomized (https://www.sealedenvelope.com/simple-randomiser/v1/lists, unique ID: 276991048306206) and double-blinded to reduce possible social facilitation bias. Experimental visits took place at the same time of day (± 1 hour), with at least seven-days between visits. Subjects abstained from heavy, strenuous exercise and alcohol consumption 24 hours prior and avoided caffeine consumption on the day of testing.

INSERT FIGURE 1 HERE

Subjects. Ethical approval was granted by the Leeds Trinity University School of Social and Health Sciences ethics committee (code: SHSS-2018-049). Subjects were over 18 years old and were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent. Sample size, calculated on the magnitude of performance effect seen in our most recent study (5) using GPower, v3.1 (University of Dusseldorf, Germany; difference between conditions 133 seconds, SD 104 seconds; effect size 1.27; power 0.95), indicated nine subjects were required to test the null hypothesis. Nine healthy, resistance trained (i.e., 12 months training experience, 3 times per week) male subjects (mean ± SD, aged 24 ± 5 years; body mass 75.7 ± 8.8 kg; height 174 ± 10 cm; 5 repetition

deadlift maximum [5RM] 132.3 ± 28.5 kg; estimated 1RM (32) 149.6 ± 32.2 kg) were recruited.

Procedures

Baseline Test - Visit One. A UK Strength and Conditioning Association (UKSCA) qualified trainer, supervised ensured correct technique was used for all lifts. Baseline tests consisted of three tasks: an estimation of deadlift 1RM (using 5RM protocol; 32), the IMLT and a familiarization task related to the DLT. The estimation of 1RM consisted of five sets of incremental five repetition lifts with the final set of repetitions completed at maximum resistance. The IMLT consisted of three maximal repetitions held for three seconds with 90 seconds standing rest between efforts. The DLT familiarization involved one set of five repetitions at 75% of the calculated 1RM established earlier in the baseline visit.

Five Repetition (RM) Protocol. Subjects arrived dressed in suitable clothing to undertake resistance exercise (e.g., T-shirt, shorts and laced training shoes). Once the test was explained, subjects donned a heart rate monitor (FT1, Polar Electro Oy, Kempele, Finland) and completed a standardized warm-up (WU) of 5-minutes sub-maximal cycling on a static exercise bike (Monark 818 static bike, Vansbro, Sweden) at 150 Watts at 70 $r.p.m^{-1}$.

A hexagonal bar was used for all dynamic deadlifts to prevent interference with wired measurement systems (in main experimental conditions). Subjects were shown a brief video clip of a hexagonal bar deadlift maneuver with the correct form. All measurement scales to assess thermal perception (thermal sensation [TS] and comfort [TC]; visits 2 and 3 only), rating of perceived exertion (RPE; 15-point scale) and readiness to train (RTT) were then explained (see Figure 1 and measurements section for details). Subjects then completed self-selected,

static and dynamic stretches, along with a series of sub-maximal dynamic (unloaded and partially loaded; 25 and 50% of self-estimated 5RM) lifts as part of a specific warm up (SWU; 3). A standardized protocol, verified by pilot tests, of fixed duration and over a maximum of 25 total repetitions was used to establish 5RM to avoid failure due to fatigue (32). One repetition maximum was not permitted institutionally due to health and safety restrictions.

Subjects commenced the 5RM protocol at 75% of their self-estimated 5RM with HR and RPE recorded in the 30 seconds after each five-repetition set. Subjects rested for three-minutes to enable recovery (3) before performing the second set of five repetitions at 85% of estimated 5RM. RPE and HR were used to set the increments of the final three sets of 5RM efforts; these were targeted to be 95, 100 and 100% (±1% increments) of 5RM adjusted in accordance with RPE and HR. The weight lifted on subjects' final completed 5RM was entered for the predicted 1RM by relative, nonlinear increments of 5RM using this equation:

Eq 1: (5RM kg*1.1307) + 0.6998 kg (32)

Predicted 1RM was used to prescribe the resistance at 75% of 1RM in the DLT for 10 repetitions to assess the performance effect of Menthol-Spray against the Control-Spray during visits two and three (3).

Isometric Lifting Task (IMLT). Subjects completed a test of their maximal isometric lifting performance by performing a mid-thigh pull maneuver with a calibrated dynamometer (TKK-5002, Type-2, TAKEI, Japan). Body position was adjusted in accordance with the subject's height to create joint angles at the hip and knee within the correct range for a mid-thigh pull; verified by goniometer for the knee (i.e., 125 to 145°) and the hip (i.e., 140 to 155°; 7). Subjects completed brief SWU attempts for three seconds at 25, 50 and 75% (perceived) intensity before

maximal attempts commenced. Immediately after each maximal attempt RPE and HR were recorded.

Familiarization. After the three-minute rest period post IMLT, subjects completed a DLT familiarization for half of the repetitions required (5 of 10 repetitions) in the main experimental conditions that occurred ~7 days later. Subjects were then asked to complete a standardized cool down period of five minutes sub-maximal cycling on a static exercise bike followed by self-directed stretching.

Experimental Trials. Subjects arrived at the strength and conditioning suite in suitable athletic clothing. In addition to RPE and Readiness to Train (RTT), subjects were also required to report their thermal perceptions for their legs (i.e., the site for spray application; TS_{legs} & TC_{legs}) at specific points throughout the visit. Subjects donned a heart rate monitor and completed the WU. They were prepared for instrumentation with EMG electrodes (Delsys Trigno LE230, Virginia, USA) placed over the rectus femoris (RF), biceps femoris (BF), and medial gastrocnemius (MG). Additionally, thermistors for the measurement of skin temperature (T_{skin}) were placed and secured by micropore tape (TransporeTM,1527-1, 3M Health Care, MN, USA) at the equivalent muscle locations on the non-dominant leg. Subjects then removed their shoes and socks, donned an oronasal face mask (to mask the fragrance of the sprays and maintain condition blinding) and were sprayed with 125 mL of either a Menthol-Spray or a Control-Spray; the investigator also wore an oronasal mask to maintain experimental blinding. The spray was delivered while subjects stood in a large plastic box to capture and measure any run-off during the spraying process (see measurements section); which took ~2-minutes. The EMG electrodes (not waterproof) were then attached at the pre-marked anatomical locations and after refitting footwear, subjects commenced their SWU of unloaded and partially loaded

dead lifts. Subjects then rested three minutes before commencing the DLT of 10 repetitions at 75% of 1RM (3). Surface EMG data were recorded throughout the DLT with RPE and HR recorded immediately after. Subjects then moved to complete the IMLT (3-minute transition), where three brief attempts at 25, 50, and 75% were completed before commencing the IMLT. Hip and knee angles were again standardized by goniometer before three, 3-seconds, maximal isometric contractions (interspersed with 90 seconds rest) were completed. RPE and HR were recorded immediately after each attempt and once all attempts were complete, all instruments were removed and a cool down procedure was then completed.

After the final visit, subjects completed semi-structured debrief conducted by an independent member of the research team (to maintain the blinding of the lead researcher). The debrief asked subjects to identify which of the visits was the Menthol-Spray and which was the Control-Spray, to provide any overall comments on the sensation evoked by the sprays and whether they viewed these sensations as ergogenic.

Description of Menthol-Spray and Control-Spray Application. All performance measures in the experimental visits were completed within the estimated chemically active period of the Menthol-Spray (within 25-minutes of spray application, 5,20). Both sprays were produced by the same independent chemical consultant as in previous studies (Chemical Associates, Rosemead, Frodsham, United Kingdom; 4,5) in accordance with our published guidelines (4). The Control-Spray contained 3% surfactants plus water, while the Menthol-Spray contained 0.20 wt/wt L-Menthol in 3% surfactants plus water. To minimize supplementary perceptual cooling associated with a spray temperature lower than T_{skin} and ambient temperature, the spray bottles containing the solutions were immersed in a temperature-controlled water bath (4YANG Digital Thermostatic Bath Water Lab), maintained at 35.5°C for one hour prior. The

bath temperature was verified by an immersed, calibrated thermistor (Grant Instruments, Cambridge [Shepreth], Cambridge, U.K). Agreement between bath and spray temperature was verified by pilot tests.

To ensure a consistent volume of spray was applied, spray volume was measured with a calibrated digital weighing scale (Sartorius Mechatronics UK Ltd, TE6100, Surrey, U.K; 1 g resolution) by measuring the pre and post-application spray bottle weight. The spray bottle aperture was unchanged throughout the study with the spray applied ~20 cm away from the skin. Spray runoff was measured from the captured run-off in the plastic box before and after spray application (Sartorius Mechatronics UK Ltd, TE6100, Surrey, U.K; 1 g resolution).

Measurements

The ambient conditions on each visit were recorded by a temperature and humidity weather station (CM9088, ClimeMET, China).

Perceptual Measurements. See Figure 1 for frequency of perceptual measurements.

Readiness to Train Scale (RTT) was assessed on a 10 cm visual analogue scale (VAS) to a 0.1 cm resolution with anchors ‘not at all ready (0 cm)’ and ‘completely ready (10 cm)’ (30). TS_{legs} and TC_{legs} were assessed using a 20 cm VAS ranging for TS from “Very Hot” (20 cm); “Hot”; “Warm”; “Slightly Warm”; “Neutral”; “Slightly Cool”; “Cool”; “Cold”; to “Very Cold” (0 cm); (44) and for TC from: very comfortable (20 cm), comfortable, just comfortable, just uncomfortable, uncomfortable, to very uncomfortable (0 cm).

Physiological Measurements

Skin Temperature (T_{skin}) was logged automatically every 30-seconds throughout each condition using a remote data logger (Squirrel 2020 series, Grant Instruments Ltd, Cambridge [Shepreth], U.K).

Muscle Electromyography (EMG). Surface muscle EMG data were generated according to the procedures of Goodall et al. (21) and in accordance with Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines (15). Surface EMG data were collected from agonist and antagonist muscles involved in the deadlift and mid-thigh pull and were the RF, BF, and MG (6,18). The anatomical locations were identified by palpation with the muscle belly mid-point identified by a segmometer with guidance from SENIAM (15). EMG electrodes were placed parallel to the muscle angle of pennation. Once located, the muscle belly was shaved, abraded and cleaned with an alcohol swab. EMG electrode placement was replicated between visits by subjects maintaining the sensor outline with a non-permanent marker pen. Surface EMG data were amplified (1000), band-pass filtered (50-500 Hz) and sampled at a frequency of 2000 Hz using the Delsys (Delsys Trigno LS850, Virginia, USA) analogue-to-digital converter. Standard EMG waveforms were generated for each DLT and IMLT muscle contraction. The waveforms were analyzed offline using Delsys acquisition programming to generate the root mean squared (rms) of each of the raw surface EMG traces.
Performance Measurements. The total number of repetitions during the DLT was used as an indication of dynamic lifting performance. Peak force (kgf) achieved during each 3-second IMLT was used as an indication of isometric lifting performance.

Statistical Analysis

Normality of data were checked using Shapiro Wilks. Test data were either analyzed according to a specific event in the protocol (i.e., related to DLT & IMLT performance), by time points

in the protocol or paired overall between condition. Mean (±SD) data were calculated for perceptual ratings (RTT, RPE, TS_{legs} & TC_{legs}), performance indices (DLT repetitions & IMLT force production), and for physiological variables (rmsEMG, T_{skin} and HR) in the Menthol-Spray and Control-Spray trials. Paired data (between condition) were compared with paired samples t-test or Wilcoxon signed ranks test. Where more than two points were considered, data were compared within-subject between condition with repeated measure analysis of variance (ANOVA). Non-spherical data, indicating unequal variance, were adjusted with Mauchly's test. Significant effects were determined post-hoc using *Fishers LSD* pairwise comparison. Partial eta squared (ηp^2) indicates ANOVA effect size. Data are reported with 95% confidence intervals for condition main effects. Analyses were conducted using SPSS (SPSS v27, IBM, Chicago, Illinois, USA) and Prism (Graphpad, Prism v6, San Diego, USA) to an alpha level of 0.05. Bayesian statistical determinants (BF_{10}) were calculated using JASP for main effects between conditions (v0.14.1, University of Amsterdam, the Netherlands).

Analysis by Protocol Event. For the DLT, the total number of repetitions was compared using the Wilcoxon signed ranks test. RPE and HR were compared between condition for the time point immediately after the DLT was complete using paired analysis. The remaining comparisons were made with ANOVA where perceptual measures (i.e. TS_{legs}, TC_{legs}) were compared within-subject between condition post-WU, post-spray application and pre-DLT. RTT was compared immediately after spraying and immediately prior to the DLT. The rmsEMG of the RF, BF and MG data were compared for the DLT during repetition 1, 5 and 10. Relating to the IMLT paired analysis was used for the time point immediately before the first IMLT effort commenced for RTT, TS_{legs}, TC_{legs} . The remaining comparisons were made by ANOVA for peak force production (kgf) during the IMLT, rmsEMG data for the RF, BF and MG for each contraction and RPE and HR recorded after each attempt.

Analysis by Time Point. T_{skin} data were normalised to the starting T_{skin} and were compared at five distinct time points (Rest, 5 min, 10 min, 15 min, 20 min) between conditions using ANOVA.

Analysis of Standardized Variables. Spray runoff, spray volume, ambient temperature and relative humidity were compared between condition by paired analysis.

RESULTS

Standardized Variables

None of the standardized variables differed between conditions. The mean (±SD) ambient temperature averaged 16.6 ± 0.7 and 17.0 ± 0.6ºC (t = 1.449, p = .185); relative humidity (RH) averaged 40 ± 6 and 40 ± 6% in (t = .532, p = .609); spray volume averaged 125 ± 7.4 and 125 ± 7.8 mL (t = .245, p = .812); and spray run-off averaged 34.8 ± 7 and 37.8 ± 8 mL (t = .274, p = .790) in the Control-Spray and Menthol-Spray conditions respectively.

Dynamic Lifting Task (DLT)

All subjects completed the full 10 repetitions in the Control-Spray and Menthol-Spray conditions (z = .000, p = 1.000). The rmsEMG response between repetitions 5 and 10 indicated a significant reduction in activity (i.e., reduced muscle recruitment) in the RF (main effect for repetitions $f_{(2, 16)}$ = 3.443, p = .050, ηp^2 = .301), nearing significance in BF (no main effect for repetitions $f_{(2, 16)}$ = 3.467, p = .090, ηp^2 = .302) but not the MG (no main effect for repetitions $f_{(2, 16)}$ = .431, p = .657, ηp^2 = .051).

Overall, this change in rmsEMG activity did not occur to any differing extent in the Control-Spray compared to Menthol-Spray condition (no main effect for condition in the RF $f_{(1,8)}$ = .028, p = .871, ηp^2 = .003, 95% CI = 2.032 to -2.351 V, BF_{10} = 1.826; BF $f_{(1,8)}$ = .270, p =

.617, ηp^2 = .033, 95% CI = 1.759 to -1.112 V, BF_{10} = .051; or MG $f_{(1,8)}$ = .052, p = .825, ηp^2 = .007, 95% CI = 2.349 to -1.925 V, BF_{10} = .013).

Nevertheless, a significant interaction was evident in BF (interaction effect $f_{(2,16)}$ = 6.196, p = .010, ηp^2 = .436) but not the RF (interaction effect $f_{(2,16)}$ = .651, p = .53, ηp^2 = .075,) or MG (interaction effect $f_{(2,16)}$ = .641, p = .540, ηp^2 = .074). Post-hoc analysis indicated higher rmsEMG activity in the BF during the 10th repetition in the Menthol-Spray condition compared to the Control-Spray condition (p = .029, 95% CI = 1.4 to -.10 V) (Figure 2A to C).

INSERT FIGURE 2 HERE

As each test condition ensued, there were changes in TS_{legs} (main effect for time $f_{(2,16)}$ = 41.165, p = .001, ηp^2 = .837) but not TC_{legs} (no main effect for time $f_{(2,16)}$ = 2.750, p = .094, ηp^2 = .256) (Table 1). Post-hoc analyses indicated that TS_{legs} decreased initially (p = .001), from a subjective rating of *warm/slightly warm* to *neutral* after spraying and then plateaued (p = .957). Despite the application of the menthol, the differences in rmsEMG activity were not evoked by changes in TS_{legs} (no main effect for condition $f_{(1,8)}$ = .876, p = .377, ηp^2 = .099, 95% CI = 2.2 to -.63 cm, BF_{10} = .334) or TC_{legs} (no main effect for condition $f_{(1,8)}$ = .510, p = .496, ηp^2 = .060, 95% CI = 2.5 to -1.3 cm, BF_{10} = .339). There was no interaction effect in TS_{legs} ($f_{(2,16)}$ = .465, p = .637, ηp^2 = .055) or TC_{legs} ($f_{(2,16)}$ = 2.068, p = .159, ηp^2 = .205).

INSERT TABLE 1 HERE

HR following the DLT was 147 ± 11 b.p.m^{-1} and 150 ± 13 b.p.m^{-1} in the Control-Spray and Menthol-Spray conditions respectively (t = -.866, p = .412, 95% CI = 5 to -11 b.p.m^{-1}, BF_{10} =

.437). Similarly, RPE after DLT was 16 ± 1 cm and 16 ± 2 cm (i.e., *hard* to *very hard*; Z = -.250, p = .803, 95% CI = 1.2 to -.94, BF_{10} = .330). RTT averaged 8.3 ± 1.8 cm and 8.2 ± 1.7 cm in the Control-Spray and Menthol-Spray conditions respectively (grand mean ± SD) which was closest to the anchor *completely ready* [to train] and were not different (no main effect for condition $f_{(1,8)}$ = .063, p = .808, ηp^2 = .008, 95% CI = .51 to -.41 cm, BF_{10} = .322), across time ($f_{(1,8)}$ = .504, p = .498, ηp^2 = .059) or showing an interaction ($f_{(1,8)}$ = .068, p = .800, ηp^2 = .008). This analysis also included the time point immediately before the IMLT.

Isometric Lifting Task (IMLT)

IMLT force production, irrespective of condition, did not decline across the three attempted isometric lifts (no main effect for attempt $f_{(2, 16)}$ = .152, p = .860, ηp^2 = .019). This sustained force production was maintained at a higher level (main effect for condition $f_{(1, 8)}$ = 6.382, p = .035, ηp^2 = .444, 95% CI = .70 to 15.4 kgf, BF_{10} =2.098) throughout the Menthol-Spray condition (grand mean ± SD; 148 ± 30 kgf) compared to the Control-Spray condition (140 ± 30 kgf) (Figure 3A). Seven of the nine subjects improved equating to 5.7 ± 9.5% (Figure 3B). The consistent nature of the IMLT performance was also reflected in a lack of interaction between repetition and condition ($f_{(2, 16)}$ = 1.461, p = .261, ηp^2 = .154).

INSERT FIGURE 3 HERE

Similar to the force production data, rmsEMG activity did not decline across each attempt of the IMLT (no main effect for attempt: BF $f_{(2, 16)}$ = 2.672, p = .100, ηp^2 = .250; RF $f_{(2, 16)}$ = 3.448, p = .057, ηp^2 = .301; MG $f_{(2, 16)}$ = 1.099, p = .357, ηp^2 = .121). The change in IMLT force production was mirrored by alterations in rmsEMG activity when condition effects were considered for the BF ($f_{(1, 8)}$ = 5.407, p = .049, ηp^2 = .403, 95% CI = .01 to 2.15 V, BF_{10} = 1.102) but not the RF ($f_{(1, 8)}$ = .001, p = .977, ηp^2 = .001, 95% CI = 2.10 to -2.11 V, BF_{10} =

.031) or MG ($f_{(1, 8)}$ = 1.560, p = .247, ηp^2 = .163, 95% CI = 4.9 to -1.47 V, BF_{10} = .204) (Figure 2D to E). Grand mean (± SD) data indicated the BF rmsEMG activity was significantly higher in the Menthol-Spray (3.8 ± 1.5 v) compared to Control-Spray condition (2.9 ± 0.34 V). Also similar to the IMLT performance data, the sustained rmsEMG activity was reflected in a lack of interaction effect (BF $f_{(2,16)}$ = 1.448, p = .264, ηp^2 = .153; RF $f_{(2,16)}$ = 1.067, p = .367, ηp^2 = .118; MG $f_{(2,16)}$ = .829, p = .454, ηp^2 = .094).

TS_{legs} was different (t = 3.598, p = .007, 95% CI = 1.75 to 8.0 cm, BF_{10} = 8.494) prior to IMLT and was lower in the Menthol-Spray condition (8.7 ± 4.5 cm) compared to the Control-Spray (13.6 ± 1.2 cm) corresponding to the descriptor *slightly cool* versus *slightly warm*. This difference in TS_{legs} did not translate to a difference in TC_{legs} (t = .820, p = .436, 95% CI = 3.7 to -1.8 cm, BF_{10} = .424) which averaged 12.3 ± 2.7 cm and 11.3 ± 3.3 cm respectively (i.e., *just-comfortable*).

On average, HR was 118 ± 1 $b.p.m^{-1}$ and 123 ± 3 $b.p.m^{-1}$ in the Control-Spray and Menthol-Spray conditions and did not differ with each IMLT attempt, irrespective of condition (no main effect for attempt $f_{(2,16)}$ = 1.821, p = .194, ηp^2 = .185), when each condition was compared (no main effect for condition $f_{(1,8)}$ = 2.085, p = .187, ηp^2 = .207, 95% CI = 2.8 to -12.3 $b.p.m^{-1}$, BF_{10} = .196) or show an interaction effect ($f_{(2,16)}$ = 1.999, p = .168, ηp^2 = .200) (Table 2). On average, RPE was 15 ± 1 and 16 ± 0 in the Control-Spray and Menthol-Spray conditions, corresponding to the worded descriptor *hard* to *very hard*. These perceptions neared being different with each attempt, irrespective of condition (no main effect for attempt $f_{(2,16)}$ = 3.512, p = .054, ηp^2 = .305), were not different between condition (no main effect for condition $f_{(1,8)}$ = 1.293, p = .288, ηp^2 = .139, 95% CI = 0.5 to -1.5, BF_{10} = .293) and did not show an interaction effect ($f_{(2,16)}$ = .591, p = .538, ηp^2 = .565).

INSERT TABLE 2 HERE

Skin Temperature (T_{skin}) Response (Time Analysis)

Prior to the spray application, T_{skin} was 30.0 ± 0.9 and 30.6 ± 0.9°C in the Control-Spray and the Menthol-Spray conditions respectively (Table 3). Despite the spray temperature being slightly above that of skin temperature (i.e. 35.5°C), the latter dropped to an average of 27.3 ± 1.1 and 27.7 ± 1.4°C by the end each condition (main effect for time $f_{(2.146, 17.16)} = 192.2$, $p = 0.001$, $\eta p^2 = 960$). The primary change in T_{skin} was seen in the first 10-minutes after spray application (Figure 4). There was no evidence of a greater change in one condition (no condition effect: $f_{(1,8)} = 2.356$, $p = .163$, $\eta p^2 = .227$, 95% CI = .81 to -.16°C) yet the Bayes factor calculation indicated the data provided moderate evidence in favor of the alternative hypothesis ($BF_{10} = 7.279$). There was no interaction effect ($f_{(2.427, 19.42)} = 0.913$, $p = .435$, $\eta p^2 = .102$).

INSERT FIGURE 4 HERE

INSERT TABLE 3 HERE

Semi-Structured Interview

Six subjects correctly identified the Menthol-Spray intervention, two incorrectly identified the Control-Spray intervention as the main treatment condition and one subject was unsure. For those who correctly identified the Menthol-Spray condition example comments included that "the second [Menthol] spray was instantly cooler, legs still feel cool, cooler than last time" whilst the perception of this effect on performance varied indicated by statements like "the [Menthol] spray made me feel more ready to train" or alternatively, "more difficult to lift this week because it was too cold – still feeling cold now" and "I didn't expect my performance to be influenced positively".

DISCUSSION

This study examined if a low concentration of menthol, applied by spray to the legs prior to weightlifting, could improve perception and performance of a dynamic and isometric lifting task. The data revealed an ergogenic effect, with concomitant increases in BF rmsEMG, for the maximal IMLT only; the hypothesis is partially supported. Yet perception was only transiently improved. This is the first study to report an ergogenic effect on *maximal* resistance training activities following the application of Menthol-Spray which can now be added to novel observations from our previous work with endurance activities (5). The mechanistic surrogates measured in the current study provide the opportunity to explore the pathway to performance facilitation.

Prior evidence from empirical studies suggests isometric muscle activation was a more plausible candidate for performance enhancement following menthol application or skin cooling (35,39,42,43). Our data correspond with the findings of Tokunaga et al. (39) who report increased rmsEMG activation after 5% menthol gel application during isometric knee extension at 35% of maximal voluntary contraction; we show this effect extends to maximal activities at lower concentrations of menthol and different application protocols (i.e., spray vs. gel). Similar effects were also noted with transient skin cooling where RFD was shown to improve (35). We could not investigate an improvement in RFD after menthol-spray application and this remains a plausible mechanism to be investigated further. Collectively, an evidence base is developing that shows skin-cooling evokes increases in muscle fiber recruitment, RFD, and isometrically generated force. Menthol evokes this more effectively and for a longer duration when compared to a representative control condition, as evidenced by the present study.

While the findings related to isometric muscle activity are convincing, evidence related to the DLT is less clear. We show sustained rmsEMG activity for the BF in the 10th repetition of the DLT relative to the Control-Spray (Figure 2B). However, the majority of our other measured variables were unchanged. Institutional health and safety restrictions did not allow for open ended DLT performance (i.e. repetitions) to failure and this may have illuminated if a performance effect was evoked; this presents an opportunity for future work. Nevertheless, our hypothesis related to possible performance enhancement for the DLT, was additionally based on evoking perceptual improvement (i.e. feeling cooler and more comfortable) and our protocol did not achieve this separation until the IMLT. Coupled with the prior literature supporting a more plausible mechanism of facilitation for isometric activities and the tentative evidence we show for DLT, we caution against supporting a benefit of Menthol-Spray to dynamic resistance exercises. In unifying our experimental observations, we speculate Menthol-Spray increases activation of muscle groups that contribute to force development in a given activity that are not the primary agonist. This might explain why the additional activation of the BF during the IMLT, which contributes approximately ~5% to force development during the mid-thigh pull compared to the RF which contributes ~20%, improved performance (24). By contrast, both the RF and BF contribute more evenly to effective deadlift performance across the ascent and descent phases of the DLT (36).

While the magnitude of T_{skin} cooling remains within the range known to increase EMG amplitude (42), the additive effect of menthol to this mechanism requires explanation. Similar to T_{skin} cooling, menthol is known to be a TRPM-8 receptor agonist (28,29,40). Therefore, when a similar magnitude of skin cooling is achieved the additive effect can be attributed to the addition of the menthol to the chemical constituents of the spray. Effects on both the peripheral and central nervous system are likely. Firstly, beyond the neuromuscular junction

(i.e, peripheral nervous system), stimulation of skin afferents by skin cooling selectively prioritized recruitment of large diameter, above small, motor units (43) to potentially boost force development. Secondly, within the central nervous system, a TRPM-8 agonist similar to menthol (icilin), increased the activation of cholinergic interneurons near the central spinal canal, which are thought to modulate motoneuron excitability (11), which is a further plausible mechanism of facilitation. Moreover, menthol was noted to mediate pain sensation (28) in a similar way to palmar cooling in accordance with gate control pain theory, with palm cooling already shown to enhance resistance exercise performance (23). Lastly, menthol is known to trigger a somatosensory feedback loop at spinal level that improves thermal perception (i.e. feelings of coolness and comfort; 8,20) through spinal relay of thermal-afferent information at the dorsal root ganglion (2) with perception of thermal environment formed in the insular cortex (14). While we only transiently improved perception in the current study, it is known this can enhance exercise performance especially in hot conditions (5). Collectively, menthol application may evoke more responsive large diameter motor units (peripheral), driven by more excited central motor neurons with enhanced thermal perception (i.e., somatosensory facilitation).

This study is not without limitation. For example, it is plausible the differences in rmsEMG are due to differences in the volume of spray applied to the front relative to the back of the legs. While care was taken to standardize the spray protocol (same volume, temperature, experimenter, duration of application and array) our protocol does not allow for this possibility to be refuted. Similarly, we included a representative control condition that thermally mimicked the menthol-spray but was biochemically distinct by the menthol constituent of the spray. While some of our previous work included a “no-spray” control, such a condition would be both thermally and biochemically distinct from the menthol-spray preventing any

demonstrable separation in our experimental effects which we do show in the present study. The "no-spray" would likely be outperformed by both the Control-Spray and Menthol-Spray intervention. Moreover, we were unable to verify any changes in muscle temperature or deep body temperature evoked by the interventions. Shimose and colleagues (35) did show muscle temperature changed fractionally (by 0.2°C from 34.9 to 34.7°C) during a cooling protocol, with prior warm-up, that lowered T_{skin} from ~32°C to 26°C. In our study T_{skin} remained well within these boundaries and showed ~3.0 ± 0.4°C drop across the conditions that suggest any change in muscle temperature in our study would also stay within the boundaries seen by Shimose et al. (35). A greater sample size may have yield more substantial inter-treatment differences; yet we met the threshold to test our hypothesis and see treatment effects in the present study. Lastly, we did not look to directly assess the efficacy of the warm-up in effectively raising deep body temperature. However, differences in TS_{legs} before and after the warm-up (data and analysis not reported above) indicate thermal perception changed from a rating of "*slightly warm"* to *"warm"* but did not alter TC_{legs} beyond a rating of "*just comfortable"*. These ratings subjectively verify our warm-up as efficacious thereby inducing these benefits to performance.

In summary, our data show for the first time an ergogenic effect, with concomitant increases in BF rmsEMG, after Menthol-Spray application prior to maximal resistance exercise. Dynamic resistance exercise was not improved although muscle activation was influenced in the hypothesized direction. Protocol limitations may have reduced our capability to reveal a performance effect although prior literature indicates any effect on dynamic lifting is less plausible. These effects were achieved with relatively small volume (~125 mL) and low concentration (0.2%) of Menthol-Spray. While our protocol enabled us to address the experimental hypothesis, additionally separating thermal perception from thermal state during

dynamic maximal lifting activities remains a priority; a higher concentration of Menthol-Spray may help illuminate the effects.

PRACTICAL APPLICATIONS

From a practical perspective we show an ecologically valid protocol combining a warmup, transient skin cooling and perceived cooling can evoke a ~6% improvement in isometric lifting performance. Indeed, this study shows the application of menthol-spray to a relatively small, less thermally sensitive body surface area (4), can still evoke perceived cooling for up to 25-minutes. While this is encouraging, the effect of the menthol-spray on the perceived "readiness to train" was not significant and, when combined with the responses to the semi-structured interview, the perceived likelihood of performance enhancement from subjects was equivocal. Specifically, the cold sensation was not perceived as a positive affect. This perception is important as it may drive the engagement with this type of intervention in the applied setting. A negative appraisal of the sensations evoked could minimize the efficacy of future studies looking to titrate the most effective menthol-spray concentration, timing of spray application and coverage of body surface area to optimize the performance, muscle activation and perceptions elicited during resistance exercise. With the application protocol in mind, we recently showed *repeated* menthol-spray application to be efficacious during endurance activities (5). However, any protocol investigating repeated menthol application prior to or during resistance exercise should consider the potential for a diminished perceptual, and possibly physiological, response for each subsequent menthol application (i.e, an habituation; 19).

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Figure Legends

Figure 1. Schematic of the experimental design and timing of measurements for the main experimental trials. List of experimental design abbreviations: WU = Warm-Up, PREP = Preparation, SPRAY = Spray Application (~timing denoted by ➖➡), SWU = Specific Warm-Up, DLT = Dynamic Lifting Task, IMLT = Isometric Lifting Task. List of measurement abbreviations: RTT = Readiness to Train, RPE = Rating of Perceived Exertion, TS = Thermal Sensation, TC = Thermal Comfort, EMG = Electromyography, HR = Heart Rate, T_{skin} = Skin Temperature, X = measurement taken.

Figure 2. Mean ± SD rmsEMG during repetitions 1,5, and 10 (panels A-C) and IMLT attempts 1,2 and 3 (panels D-F) in the Control-Spray (black bars) and Menthol-Spray (grey bars) conditions; * indicates significant difference, ANOVA effects indicated in text (n = 9).

Figure 3. Mean ± SD IMLT force production (kgf; panel A) and change in force production (kgf) for each subject (panel B) in the Control-Spray and Menthol-Spray conditions; panel A * indicates significant difference, ANOVA effects indicated in text; panel B (———) denotes mean of each condition (n = 9).

Figure 4. Mean ± SD IMLT change (Δ) in T_{skin} throughout each test condition (n = 9).

Table Legends

Table 1. Mean (± SD) TS_{legs}, TC_{legs} and nearest worded descriptor on each 20 cm visual analogue scale at discrete protocol stages during the Control-Spray and Menthol-Spray conditions (n = 9).

Table 2. Mean (± SD) HR and RPE following each IMLT attempt in the Control-Spray and Menthol-Spray conditions; nearest worded descriptor relevant to RPE only (n = 9).

Table 3. Mean (± SD) T_{skin} at discrete protocol stages during the Control-Spray and Menthol-Spray conditions (n = 9).