

Menthol Mouth Rinsing Improves Cycling Performance in Trained Adolescent Males Under Heat Stress

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Purpose: This study investigated the effect of menthol (MEN) mouth rinsing (MR) on cycling performance during a modified variable cycle test (M-VCT) in adolescent athletes under hot conditions ($31.4 \pm 0.9^\circ\text{C}$, $23.4 \pm 3.7\%$ relative humidity). **Methods:** Trained adolescent male cyclists ($n = 11$, 16.7 ± 1.3 years, height 176.6 ± 8.8 cm, body mass 65.8 ± 11.6 kg, maximal oxygen uptake 62.97 ± 7.47 ml·kg⁻¹·min⁻¹) voluntarily completed three trials (familiarization and two experimental) of a 30-min M-VCT, which included five 6-min laps consisting of three 6-s accelerations and three 10-s sprints throughout each lap. In a randomized crossover design, MEN (0.01%) or placebo (PLA) (crystal-light), was swilled for 5 s before the start of each lap (total of 6 MR). Power output, distance (in kilometers), core temperature, heart rate, perceptual exertion, thermal stimulation (thermal comfort and thermal sensation), and blood lactate concentration were recorded. **Results:** MEN MR significantly improved M-VCT mean power output by $1.81 \pm 1.57\%$ compared to PLA (MEN, 177.8 ± 31.4 W; PLA, 174.7 ± 30.5 W, $p < .001$, 95% confidence interval [1.73, 4.46], $d = 1.53$). For maximal intermittent sprints, 6- and 10-s mean power output was significantly higher with MEN than PLA (6 s, $p = .041$, 95% confidence interval [0.73, 27.19], $d = 0.71$; 10 s, $p = .002$, 95% confidence interval [11.08, 35.22], $d = 1.29$). There was no significant difference in core temperature, heart rate, blood lactate concentration, or any perceptual measure between trials ($p > .05$) despite significantly higher work with MEN. **Conclusion:** 64% of athletes (7/11) improved M-VCT performance with MEN. The results of this investigation suggest that a MEN MR may improve power output during a sport-specific stochastic cycling task in elite adolescent male cyclists.

Keywords: youth, hot, trained, biking

Researchers have long been discussing the concepts of thermal perception, fatigue, and the ability to overcome various limitations to exercise performance in extreme environments (Amann, 2011; Nybo, 2010). This has led to increased interest in the use of safe, cost-effective, and viable interventions that may benefit cycling in hot environmental conditions (Amann, 2011; Barwood et al., 2020; de Korte et al., 2021). Menthol (MEN), an organic compound derived from peppermint that often presents as a flavor molecule to target the gustatory system and oropharyngeal thermoreceptors, has been used to elicit responses in reward centers of the brain as a potential way to improve exercise performance (Eccles, 2000; Guest et al., 2007). MEN's proposed mechanism of action appears to be via the activation of the transient receptor potential melastatin-8 and subsequent downward effects on the central drive mechanism (Bharate & Bharate, 2012; Eccles, 2000; Guest et al., 2007). Although it has been demonstrated that MEN rinsing does not prevent heat gain or reduce core temperature (T_c) during exercise, it can affect thermal perception along with perceived exertion, which are variables shown to enhance performance independent of an athlete's physiological or thermal state (Jeffries et al., 2018; Stevens et al., 2016, 2017). This suggests that as long as signs and symptoms of heat-related illness(es) are minimized, MEN may play a role in extending performance time or benefiting power output during moderate-to-intense endurance exercise tasks (Crosby et al., 2022; Gavel et al., 2021, 2023; Stevens & Best, 2017).

Methodological differences across current research indicate that no standardized or best practice approach to utilize MEN orally

currently exists in regard to frequency of "swilling" (single vs. repeated) and rinse concentration (0.01%, 0.05%, or 0.1%), with no research on the dose-response relationship between MEN swilling and performance (Jeffries & Waldron, 2019; Stevens & Best, 2017). While various dosages (swill frequency and concentration) have demonstrated some utility, it may be more practical to consider the potential benefits of repetitive rinsing as MEN are transitioned out of the laboratory and into the field of competition. For instance, many cycling race disciplines (road, mountain, criterium, etc.) have now adopted course structures to accommodate spectators, whereby races often consist of multiple laps on a shorter circuit (Sharma et al., 2020). This presents an opportunity for athletes to carry one water bottle per lap, minimizing extra weight, while swapping the bottle each lap in the feed zone allowing for a small "swill" of MEN per lap. Since the practice of utilizing MEN on multiple occasions throughout a race has only been adopted by a small number of competitive athletes, this should be further explored.

Furthermore, the recent development of a stochastic cycling protocol, known as the variable cycle test (VCT), offers a new opportunity to capture different parameters that better relate to the dynamic and repetitive power demands of cycling race events, making it a potentially useful and reliable predictor for the performance-related qualities required for competition (Sharma et al., 2015, 2020). Since the 1-hr VCT reproduces the demands of elite-level racing for adults with a coefficient of variation (CV) of 1.24% (Sharma et al., 2015), a modified version of the protocol (30-min modified variable cycle test [M-VCT]) for a junior population may offer a reflection of the duration and intensity typical of adolescent-level cycling events (Birat et al., 2018; Falk & Dotan, 2011). Performance capacity in young people is of interest due to the

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thermoregulatory and physiologic differences found between trained adolescents and adults (Falk & Dotan, 2011). Adolescent athletes are known to rely on dry thermoregulatory heat exchange to regulate internal and peripheral temperature (due to greater surface-area-to-mass ratios), while older adults utilize evaporative heat loss strategies for cooling (Falk & Dotan, 2011). It is also suggested that fatigue may influence athletes differently, depending on training and experience (Birat et al., 2018); yet activation of transient receptor potential melastatin-8 thermoreceptor and stimulation of the central nervous system after fatigue has not been explored across age cohorts and it is unknown if adolescents respond differently to MEN (Bharate & Bharate, 2012). The purpose of this study is to assess the effects of repeated (total of six swills) MEN mouth rinsing (MR) (0.01%) on performance and perception in trained adolescent male cyclists during a M-VCT in the heat.

Methods

Participants

A group of trained adolescent males ($n = 11$) aged between 15 and 19 years volunteered for the study (age 16.7 ± 1.3 years, body mass 65.7 ± 11.6 kg, height 176.6 ± 8.8 cm, average weekly training 11.9 ± 3.2 hr, maximal oxygen uptake [$\text{VO}_{2\text{peak}}$] 63.0 ± 7.5 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). All athletes were recruited from local cycling clubs and provided verbal and written informed consent prior to participating, and parental consent was provided for participants aged less than 18 years. Athletes were instructed to repeat their weekly training load for the duration of the study, as well as abstain from vigorous exercise 24 hr before sessions. Each participant replicated their diet in the 24 hr preceding each laboratory session. This study was approved by the Research Ethics Board of Ontario Tech University (REB#16331).

Study Design

This single-blind, cross-over experimental investigation consisted of five laboratory sessions, separated by 3–7 days (Figure 1). The tests included a maximal incremental cycle test, and familiarization of the cycle protocol before repeating the M-VCT performed with MEN or placebo (PLA) MR. All tests were performed at the same time of day and on the same cycle ergometer (LODE Excalibur Sport, Quinton Instrument). Upon arrival to each session, participants voided their bladder and provided a small midstream urine

sample to determine hydration status by way of urine-specific gravity (< 1.020) using a calibrated portable refractometer (Atago). Participants were then weighed on a calibrated body mass scale (Weigh Beam Eye-Level, DETECTO) before and after each cycling session after being towel dried and in their cycling bottoms to determine sweat loss. Participants were instructed to refrain from consuming fluids during each trial. Sweat loss was calculated using the following equation: Sweat loss (L) = body mass (kg) + fluid intake (L) – urine output (L) (Broad et al., 1996).

Preliminary Testing and Familiarization

Participants performed a maximal aerobic capacity test on a cycle ergometer (Excalibur Sport; Lode BV) in temperate conditions (20°C ; 30% relative humidity [RH]) to determine $\text{VO}_{2\text{peak}}$, peak power output, and ventilatory thresholds. Body mass (in kilograms), height (in centimeters), and environmental conditions were recorded before exercise. The incremental test started at 25 W and increased by 25 W every 1 min until voluntary exhaustion. Heart rate (HR) was monitored continuously, and rating of perceived exertion (RPE, Borg 6–20; Borg, 1982) was recorded at the conclusion of each 1-min stage. The session was terminated at volitional fatigue or once the participant could no longer maintain a minimum cadence of ~ 80 rpm for the assigned workload for a total of 30 s. Cardiorespiratory-metabolic variables were measured throughout the test using a calibrated spiro-ergometry system (METAMAX 3B, Cortex), the reliability of which has been established (Vogler et al., 2010). The test was analyzed using 30-s average breath-by-breath VO_2 values from each stage, as previously described (Beltz et al., 2016). $\text{VO}_{2\text{peak}}$ was defined as the highest 30-s average in the test (Beltz et al., 2016). Peak power output was recorded as the maximum power sustained for the final 30 s of the test. At completion, participants cooled down for 5 min at 0.5 W/kg. Following the incremental $\text{VO}_{2\text{peak}}$ test, participants rested for 20 min before completing a shortened familiarization session of the VCT (M-VCT), which is the cycling protocol used for each of the experimental sessions. Participants were asked to perform a standardized 10-min warm-up followed by five laps of the M-VCT.

Modified Variable Cycle Test (M-VCT)

The M-VCT, a modified version of the previously validated 1-hr VCT protocol in trained male cyclists (with test-retest reliability = 1.24%; Sharma et al., 2015, 2020), consisted of 5×6 -min laps that

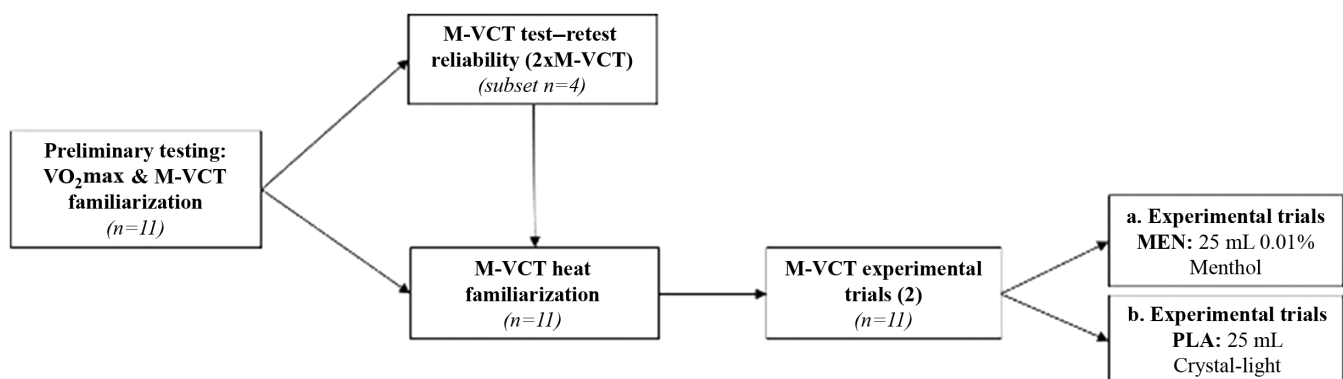


Figure 1 — Schematic of study design. M-VCT = modified variable cycle test; MEN = menthol; PLA = placebo.

were completed in a continuous and repetitive fashion. Each 6-min lap consisted of sections of varying duration and intensity, with approximately 40% of the trial prescribed at a submaximal intensity of 3.0 W/kg, while the remaining 60% of the test consisted of self-paced periods where the participant cycled at levels prescribed to be “recovery,” “hard,” “accelerating,” or “decelerating” (Figure 2). Participants were instructed to closely follow the autonomous M-VCT protocol displayed on the computer screen placed in front of the experimental bike which prompted them to work, sprint, and/or rest. Participants were instructed to complete the protocol to the best of their ability and were blinded to all dependent variables. Participants received verbal and visual instruction on how to subjectively assess RPE (Borg 6–20; Soriano-Maldonado et al., 2014), thermal sensation (TS), and thermal comfort (TC; Ramspeck et al., 2004). HR (Polar® H7 heart sensor), T_c (CORE, greenTEG AG; Verdel et al., 2021), power output (in watts), and distance (in kilometers) were recorded continuously, whereas RPE, TS, and TC were collected every sixth minute at the end of each lap.

A participant’s ability to reliably cover a similar distance and perform a comparable amount of work for the two test–retest sessions was judged by a CV (Hopkins, 2000, 2015). The CV was then used to calculate the least significant change (LSC) with 95% confidence per variable using the equation $1.96 (CV/\sqrt{n}) \times \sqrt{2}$, where n = number of trial replicates (Sharma et al., 2015). This value served as the reference point to be exceeded in future sessions before performance change could be considered true (Jeffries et al., 2018; Sharma et al., 2015). Distance completed (in kilometers) and mean power output (in watts) during the M-VCT had low random error with a CV of 0.45% ($p = .234$) and 0.46% ($p = .083$), respectively, over the test–retest sessions. Average power output (in watts) during the 6- and 10-s performance sections revealed no significant difference and demonstrated high reliability (6 s: $p = .295$, CV = 0.67%; 10 s: $p = .646$, CV = 1.55%), and no significant difference was found between any performance variables

including HR (bpm; $p = .086$), T_c (°C; $p = .971$), blood lactate concentration [BLa] (mmol/L, $p = .269$), or perceptual measures (RPE, $p = .082$; TS, $p = .527$; T_c , $p = .298$). Finally, the LSC% revealed that the M-VCT could detect a 0.90% change in mean power output with 95% confidence based on the CV observed between the two trials. While the use of a small athlete cohort for reliability testing may be considered a weakness of this investigation, it can be noted that this analysis was actually used to dampen the effects of MEN MR, thereby intending to provide a more conservative or realistic estimate of performance-related improvement compared with what has been previously reported by the literature (Gavel et al., 2023).

M-VCT Heat Familiarization

A single M-VCT heat familiarization session was performed by each participant to ensure they were aware of the demands of the test when completed under hot environmental conditions (31.2 ± 0.8 °C, $23.0 \pm 2.0\%$ RH) and to minimize the potential for a learning effect of the M-VCT (Hibbert et al., 2017). Following preliminary measures (urine-specific gravity and body mass in kilograms), athletes rested in the heat chamber for 20 min before collecting baseline HR and T_c . The participant then mounted the bike to complete the standardized warm-up and the M-VCT. HR, T_c , power, and distance were recorded continuously. Perceptual measures (RPE, TS, and TC) were collected at rest, then at 6-min intervals during exercise. During this session, participants were also given instructions and practiced using a MR. 25 ml of room temperature water was rinsed on six occasions. The first rinse occurred 60 s prior to beginning the M-VCT, then at the beginning of each new lap (Laps 2, 3, 4, and 5), and finally 30 s prior to the final sprint at the end of the M-VCT. Participants were instructed to swill the rinse in the oral cavity for 5 s before expelling it into a container. No solution was swallowed.

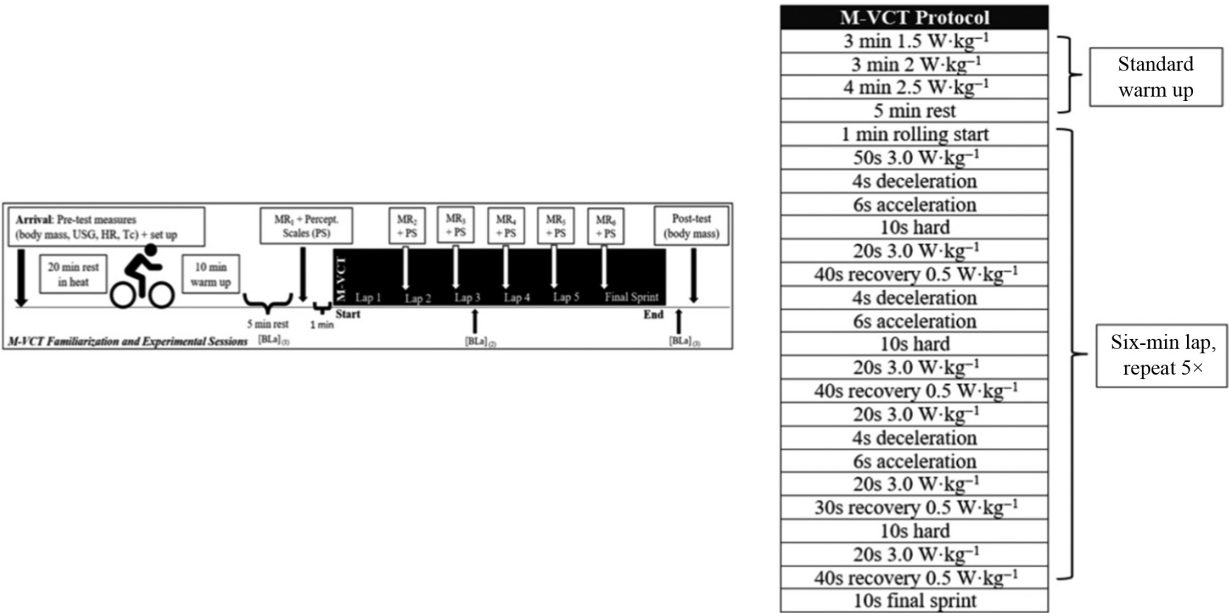


Figure 2 — Schematic of the familiarization and experimental testing design and the specific details of the M-VCT warm-up and per lap testing protocol. M-VCT = modified variable cycle test; USG = urine specific gravity; HR = heart rate; T_c = core temperature; MR = mouth rinse; PS = perceptual scale; [BLa] = blood lactate concentration.

MEN/PLA Experimental Sessions in the Heat

In following, two randomized, single-blind, cross-over experimental sessions were conducted in the heat ($31.4 \pm 0.9^\circ\text{C}$, $23.4 \pm 3.7\%$ RH; Figure 1). The exercise protocol was identical to that used during the heat familiarization session, including the collection of physiological and psychological variables. Additionally, blood lactate concentration was measured at three points from a small (3 μL) fingertip capillary blood sample using a portable lactate analyzer (EDGE Lactate Analyzer, The EDGE) following the warm-up, at the midpoint of the protocol (16-min mark), and 3 min after the test (Goodwin et al., 2007). During these sessions, participants swilled a 0.01% L-Menthol solution ([0.64] mM; Sigma Aldrich, Merck KGaA) formulated from 0.1 g of MEN crystals dissolved in 1 L of deionized water heated to 40°C (Barwood et al., 2020; Gavel et al., 2021; Stevens & Best 2017) or a PLA solution made using deionized water and a noncaloric berry flavored sucralose sweetener (Crystal Light) at six points throughout the M-VCT, as previously described (Figure 2). In addition to blinding, MR solutions were volume, temperature (warmed to $>22^\circ\text{C}$ to prevent activation of TRMP8 via cold temperatures), and color matched using a blue non-caloric edible food coloring (Club House, McCormick & Company) to prevent bias. Deception was utilized to conceal the true purpose of the study as participants were not made aware of MEN possible ergogenic properties but, rather, were asked if they preferred one MR flavor over the other. Performance results from the experimental sessions were then normalized to the variation of the M-VCT determined during test–retest sessions.

Statistical Analysis

All variables were screened for normality using Shapiro–Wilk test, z score for skewness and kurtosis of ± 3 . Paired samples t -tests were used to determine single parameter differences between variables. Reliability was established in which the technical error of measurement was calculated after changes in the mean between repeated measurements were controlled for (Hopkins, 2000, 2015). Data were log-transformed to yield variability as a percent of the mean (CV%), a natural metric for measures of athletic performance (Hopkins, 2000, 2015; Hopkins et al., 2009). The CV was then used to calculate the LSC with 95% confidence per variable using the equation $1.96 (CV/\sqrt{n}) \times \sqrt{2}$, where n = number of trial replicates (Sharma et al., 2015). This LSC served as the reference point to be exceeded before a change in performance was considered practically meaningful or beyond day-to-day biological variation (Jeffries et al., 2018). Two-way repeated-measures analysis of variance was used to assess the effects of time, trial condition, and Time $\times$ Trial condition interactions. In the event of a significant time effect, further pairwise comparisons were made using Bonferroni post hoc correction factor to determine significant differences between time points. Time versus condition ordinal data were evaluated using the Friedman test, and singular differences were detected using the Wilcoxon Signed-Rank test, set at $p = .008$. Data are reported as mean $\pm$ SD. For all statistical tests, significance was assumed at an alpha level of $<.05$, and 95% CIs of the mean difference were reported. Effect sizes for paired t tests are reported as standardized mean differences (Cohen's d) and interpreted based on Cohen's criteria: 0.2 = small, 0.5 = moderate, 0.8 = large effect (Hopkins et al., 2009). Effect sizes for analysis of variance models are reported as partial eta squared (η_p^2) and reference values were interpreted as .01 = small, .06 = moderate, and .14 = large effect

(Hopkins et al., 2009). Statistical analysis was performed using the SPSS IBM (version 28).

Results

MEN/PLA Experimental Sessions in the Heat

All data were normally distributed, and no order effect was observed between first and second trials ($p = .763$). No significant differences existed in environmental conditions between the MEN and PLA trials (MEN, $31.34 \pm 0.68^\circ\text{C}$, PLA, $31.35 \pm 0.61^\circ\text{C}$, $p = .961$, 95% confidence interval [CI] $[-0.41, 0.39]$, $d = 0.015$; MEN, RH $23.55 \pm 2.46\%$, PLA, $23.27 \pm 2.76\%$, $p = .588$, 95% CI $[-0.81, 1.36]$, $d = 0.169$). Additionally, there was no significant difference in MR temperature between MEN and PLA conditions (MEN, $25.16 \pm 1.26^\circ\text{C}$, PLA, $25.96 \pm 1.73^\circ\text{C}$, $p = .182$, 95% CI $[-2.06, 0.45]$, $d = 0.433$). All athletes arrived at the laboratory in an euhydrated state with urine specific gravity <1.020 (MEN, 1.003 ± 0.002 ; PLA, 1.004 ± 0.003 , $p = .714$, 95% CI $[-0.0013, 0.0009]$, $d = 0.114$). Total body sweat loss indicated no significant difference between MEN and PLA conditions (MEN, 0.88 ± 0.43 L; PLA, 0.83 ± 0.38 L, $p = .402$, 95% CI $[-0.08, 0.19]$, $d = 0.26$).

Cycling Performance

A significant difference in cycling performance was found between the MEN versus PLA trial ($p = .004$, $\eta_p^2 = .584$), distance completed across time ($p < .001$, $\eta_p^2 = .972$), and for the interaction between MR and distance completed during the M-VCT ($p = .029$, $\eta_p^2 = .338$). Total distance completed during the M-VCT was significantly greater for MEN compared with PLA (MEN, 21.81 ± 3.81 km; PLA, 21.48 ± 3.69 km, $p = .002$, 95% CI $[156.52, 508.35]$, $\eta_p^2 = .639$), representing a $1.1 \pm 1.0\%$ increase in total distance covered when corrected for test–retest reliability. Likewise, the cumulative distance covered per lap was significantly different between MEN and PLA for Lap 3 ($p = .046$, 95% CI $[3.71, 371.05]$, $\eta_p^2 = .341$), Lap 4 ($p = .008$, 95% CI $[81.14, 420.36]$, $\eta_p^2 = .520$), Lap 5 ($p = .002$, 95% CI $[150.05, 515.90]$, $\eta_p^2 = .622$) with greater distance completed for MEN.

Power Output—Mean, 6- and 10-s Averages

A significant difference in power output was found between the MEN versus PLA trial ($p < .001$, $\eta_p^2 = .708$), but not across time ($p = .260$, $\eta_p^2 = .126$), nor for the interaction between MR and power output across time ($p = .649$, $\eta_p^2 = .034$).

Power output data was then analyzed according to key performance sections. (a) Mean power output for the entire M-VCT was significantly higher in the MEN condition by $1.81 \pm 1.57\%$ (corrected value based on CV) when compared to PLA (MEN, 177.8 ± 31.4 W; PLA, 174.7 ± 30.5 W, $p < .001$, 95% CI $[1.73, 4.46]$, $d = 1.53$; Figure 3a). (b) Mean 6-s (acceleration) power output for MEN was significantly higher when compared with PLA (MEN, 272.8 ± 73.5 W; PLA, 258.8 ± 61.8 W, $p = .041$, 95% CI $[0.73, 27.19]$, $d = 0.71$; Figure 3b). (c) Mean 10-s (hard) power output was also significantly different between MEN and PLA, with higher power output for MEN (MEN, 710.3 ± 157.8 W; PLA, 687.1 ± 150.8 W, $p = .002$, 95% CI $[11.08, 35.22]$, $d = 1.29$; Figure 3b), but no significant difference in mean power output between conditions was found during the final sprint of the M-VCT (POsprint; MEN, 972.9 ± 234.9 W; PLA, 952.9 ± 216.5 W,

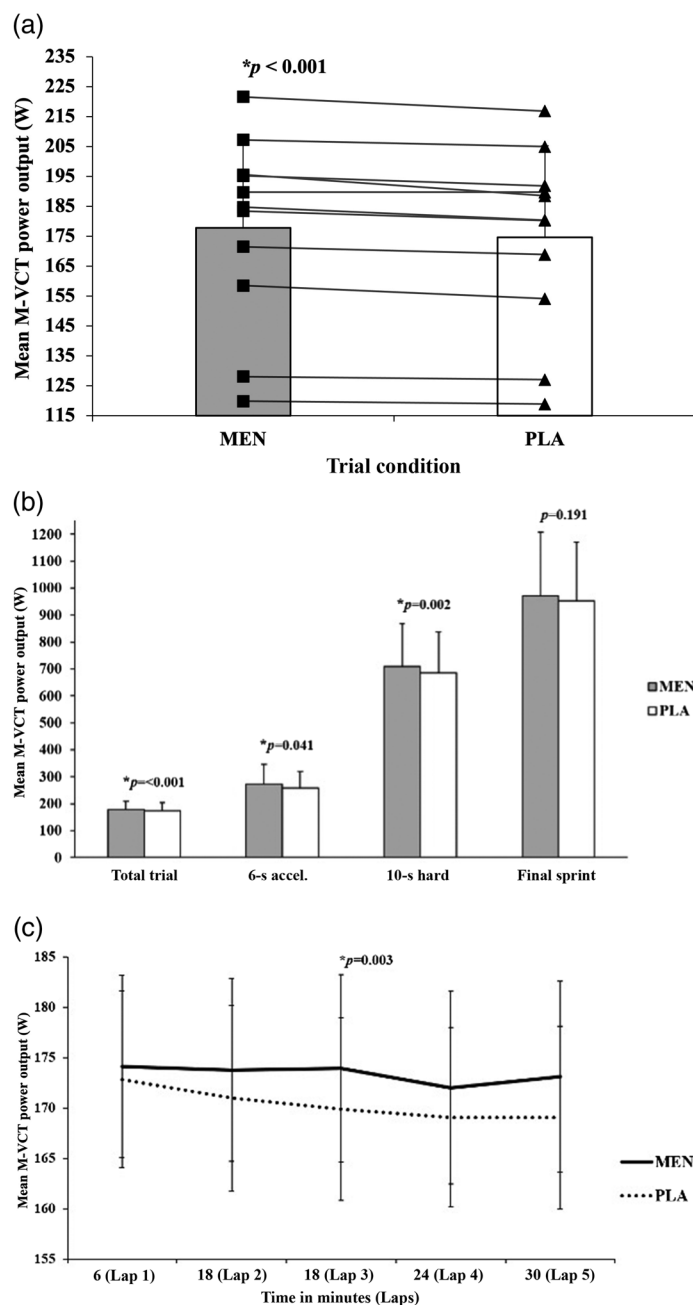


Figure 3 — Mean power output during the M-VCT as (a) including individual responses, (b) displayed according to key performance sections, and (c) across cycling time (laps). Data are mean $\pm$ SD ($n = 11$). *Significantly different between the MEN versus PLA trials ($p < .05$). MEN = menthol; PLA = placebo; M-VCT = modified variable cycle test.

$p = .191$, 95% CI $[-11.79, 51.79]$, $d = 0.42$; Figure 3b). Finally, power output was significantly different between MEN and PLA per lap (POLap_avg; MEN, 173.4 ± 29.7 W; PLA, 170.4 ± 28.8 W, $p < .001$, 95% CI $[1.66, 4.40]$, $\eta_p^2 = .71$), with a specific difference found during Lap 3, and higher power output for MEN ($p = .003$, 95% CI $[1.69, 6.41]$, $\eta_p^2 = .594$; Figure 3c).

Overall, the mean difference in power output performance between MEN and PLA was determined to be an unadjusted improvement of $2.24 \pm 1.67\%$. After applying M-VCT CV results (0.46%) the true or adjusted change in performance between MEN

and PLA conditions is $1.81 \pm 1.57\%$, a value that surpasses the 0.90% predefined LSC, to indicate that a meaningful change has occurred. Data are reported as absolute power (W) to better represent power differences between trials, values can be converted to power-to-weight ratios (W/kg) by dividing absolute power by body mass (in kilograms).

Cardiovascular and Thermoregulatory Responses

HR significantly increased as a function of exercise time in both trials ($p < .001$, $\eta_p^2 = .896$). There was no significant difference in mean or max HR between trials (mean: MEN, 164.6 ± 14.9 bpm, PLA, 163.4 ± 15.6 bpm, $p = .208$, 95% CI $[-0.83, 3.38]$, $d = 0.41$; max: MEN, 186.5 ± 12.3 bpm, PLA, 185.8 ± 11.6 bpm, $p = .451$, 95% CI $[-1.17, 2.45]$, $d = 0.24$).

T_c significantly increased as a function of exercise time in both trials ($p < .001$, $\eta_p^2 = .836$). There was no significant difference in mean or max T_c between trials (Mean: MEN, 37.58 ± 0.25 °C, PLA, 37.69 ± 0.35 °C, $p = .258$, 95% CI $[-0.34, 0.10]$, $d = 0.36$; Max: MEN, 38.06 ± 0.30 °C, PLA, 38.11 ± 0.48 °C, $p = .647$, 95% CI $[-0.31, 1.20]$, $d = 0.14$).

Perceptual Scales

RPE, TC, and TS all increased significantly as a function of exercise time (per lap; $p < .001$). Mean values for each perceptual scale were not significantly different between trial conditions across any time points (RPE: MEN, 13.27 ± 1.35 , PLA, 13.27 ± 1.62 , $p = 1.000$; TC: MEN, 1.55 ± 0.52 , PLA, 1.64 ± 0.50 , $p = .046$; TS: MEN, 1.64 ± 0.50 , PLA, 2.00 ± 0.45 , $p = .564$).

Blood Lactate Concentration

BLa increased as a function of exercise time in both trials ($p < .001$, $\eta_p^2 = .899$), with [BLa] significantly increasing from rest (pre) to the mid-trial measurement for both MEN and PLA trials (pre-MEN, 1.71 ± 0.77 mmol/L, mid-MEN, 9.21 ± 2.31 mmol/L, $p < .001$, 95% CI $[-9.32, -5.68]$; pre-PLA, 1.61 ± 0.55 mmol/L, mid-PLA, 8.09 ± 1.75 mmol/L, $p < .001$, 95% CI $[-7.98, -4.98]$). There was no significant change in [BLa] from the mid- to posttrial measurement for either trial condition (mid-MEN, 9.21 ± 2.31 mmol/L, post-MEN, 8.87 ± 2.37 mmol/L, $p = 1.00$, 95% CI $[-1.97, 2.65]$; mid-PLA, 8.09 ± 1.75 mmol/L, post-PLA, 8.76 ± 2.45 mmol/L, $p = .873$, 95% CI $[-2.40, 1.06]$).

There was no significant difference found for mean or maximum [BLa] between MEN and PLA conditions (mean-MEN, 6.60 ± 1.52 mmol/L, mean-PLA, 6.15 ± 1.30 mmol/L, $p = .158$, 95% CI $[-0.21, 1.09]$, $d = 0.46$; max-MEN, 10.12 ± 2.13 mmol/L, max-PLA, 9.31 ± 2.07 mmol/L, $p = .120$, 95% CI $[-0.25, 1.87]$, $d = 0.512$), or across rinse and time interactions ($p = .227$, $\eta_p^2 = .138$).

Individual Responses

Real performance change (corrected using the test-retest CV) from MEN was ranged from 0.29% to 5.06% (Figure 4). Seven of 11 (64%) participants were positive responders to MEN such that performance improvement exceeded the 0.9% LSC. Although the four remaining participants fell below the LSC, it should be noted that MEN did not hinder performance. Of the seven positive responders, five demonstrated $>1.8\%$ improvement (above the mean), while two participants fell below the mean improvement value. Figure 4 demonstrates individual responsiveness to MEN on

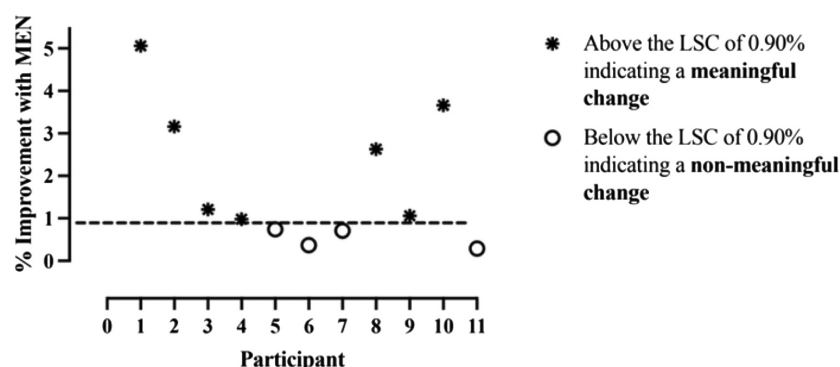


Figure 4 — Individual percent (%) improvement with MEN in relation to the 0.90% LSC threshold. 4/11 participants did not have meaningful improvement, while 7/11 surpassed this threshold, demonstrating with 95% confidence, that performance improvement was due to MEN. MEN = menthol; LSC = least significant change.

M-VCT performance with 4/11 participants demonstrating no practical improvement in performance, 1/11 with a 0.98% improvement, two participants with a 1.1% and 1.2% improvement respectively, and four participants demonstrating a performance improvement of 2.6%, 3.2%, 3.7%, and 5.1%.

Discussion

This study aimed to determine the effects of MEN MR (0.01%) compared with a PLA on performance and perception during a simulated junior cycling race (M-VCT) in trained adolescent male cyclists. Results of this study suggest that M-VCT performance in the heat is improved by MEN rinsing when compared with a PLA, as demonstrated by moderate to large effect sizes and significant differences in power output between MEN and PLA in the later stages of the M-VCT. Results also show that thermoregulatory responses (HR, T_{re}) along with blood lactate, and perceptual measures (RPE, TS, and TC) do not differ between conditions.

Menthol and M-VCT Performance

The results from this study are consistent with previous research (Crosby et al., 2022; Flood et al., 2017; Gavel et al., 2021; Jeffries et al., 2018; Jeffries & Waldron, 2019; Mündel & Jones, 2010; Stevens & Best, 2017) suggesting that MEN MR improves cycling performance in the heat by ~1.8% in trained athletes. Specifically, this study demonstrates a significant increase in power output during the latter stages of a 30-min high-intensity variable cycling task in adolescent male cyclists, a sample population yet to be researched. The results are in line with the published literature investigating set workload performance tasks; for instance, Jeffries et al. (2018) administered a single MEN rinse during the latter stages (~85% of the task) of exercise which resulted in ~6% increase in cycling performance. While this change in performance is significantly greater than the “uncorrected” 2.2% change observed between MEN and PLA in this study, the authors do indicate that since this 6% change exceeded the typical error of a time to exhaustion cycling test (CV% = 4.3%), then a true change of ~1.7% may be more representative of the true effect of MEN, this being an improvement comparable to this investigation (1.8%). Of interest is the difference in MEN frequency (one vs. six swills) and timing (swill at 85% of task completion vs. swill at the start of each lap) between the Jeffries et al. (2018) study and the present study, respectively, yet the mean (true) performance improvement

(~1.7%) was similar. Despite the similarities between the two studies in the magnitude of performance change with MEN, our results demonstrate a performance improvement with repeated MEN as early as ~15 min of high-intensity variable cycling, with no significant effects prior to Lap 3 (<15 min). What is not known from our results is whether a single dose of MEN could elicit the same performance effect as seen with the aforementioned study or whether there exists a synergistic effect of repeated MEN swills on performance. Ultimately, more research is needed to examine the utility of MEN and the relationship to frequency and timing of swills, along with the interaction of exercise fatigue and the proposed ergogenic effect of MEN.

More recent work demonstrates that rinsing MEN prior to a 3-min maximal cycling task in the heat resulted in the maintenance of relative power output for a longer duration when compared with cold water or PLA (Crosby et al., 2022). While only small to moderate differences were observed, these results highlight the potential for MEN to benefit higher intensity, short duration efforts during variable cycling tasks. Comparably, findings from the present study showed that MEN rinsing improved power output during the mid-to-final stages of a variable cycling task, as expressed by moderate to large effect sizes for “acceleration,” ($d = 0.71$) and “hard” ($d = 1.29$) work sections during Laps 3 and 4 of the M-VCT. This result supports the utility of MEN MR during hard and long exercise tasks characterized by potentially higher levels of central fatigue (Amann, 2011; Klasen et al., 2012; Meeusen et al., 2006; Nybo, 2010; Thomas et al., 2015).

Menthol and Perceptual Responses

Within the context of this investigation, it can be noted that participants were able to adopt a higher work rate and perform better under the MEN condition without reporting a higher level of perceived effort, thermal discomfort, or thermal strain. Findings from the perceptual scales utilized indicate that MEN MR during a dynamic race-like task in the heat may help to maintain, rather than improve, an athlete’s perceptual state, which still appears to benefit work capacity. This is of interest because across time, high-intensity exercise (tasks often known to feel hard or more fatiguing) are typically associated with decreased affective valence and reduced motivation to sustain a given workload (Beltz et al., 2016; Ekkekakis et al., 2011; Nybo, 2010), our data demonstrated that MEN may offer a degree of perceptual stability during difficult physically exhausting tasks without additional decline across

perceptual states. Using additional measures of central nervous system activity may offer better insight into the level of fatigue as well as the athletes' desire to stay engaged with an exercise task when MEN is used (Ekkekakis et al., 2011; Jeffries et al., 2018). Jeffries et al. 2018 suggests that the actions of l-MEN may be more complex than previously postulated in the sports performance literature and that cooling sensations conferred to the athlete are, perhaps, co-joined with "distractors" from the stressful thermal and physiological cues. These "distractors" may provide rationale for the individual variability in response to MEN seen in this study. Ultimately, further research into MEN psychological applicability for race-like tasks is needed.

Menthol and Physiological Parameters

This study monitored changes in T_c , HR, and [BLa] to provide a comparison of responses between MEN and PLA conditions. Results from this study indicate that T_c , HR, and [BLa] concentrations did not differ in mean or maximum values between trials. These findings are consistent with other research suggesting that MEN acts as a nonthermal ergogenic intervention, whereby MEN may not have an effect on T_c or HR response during exercise (Barwood et al., 2020; Gavel et al., 2021; Jeffries et al., 2018; Stevens & Best, 2017). Collectively, investigators report that T_c and HR increase in proportion to either the work performed, or the heat load experienced by the athlete, but not in relation to the use of different MR interventions (Crosby et al., 2022; Gavel et al., 2021; Gibson et al., 2019; Jeffries et al., 2018; Riera et al., 2014). Although this study did not include measurements of neurochemical biomarkers to better understand MEN's mechanistic pathway and its ability to disrupt the fatiguing process during exercise, future investigations should explore the sensitivity of using novel physiologic measures including electromyography, pupillary dilation, and electroencephalography to better describe and predict the central and peripheral effects of rinsing MEN (Amann, 2011; Meeusen et al., 2006; Thomas et al., 2015).

The Possibility of an Individualized Advantage

Some previous investigations have demonstrated the efficacy of MEN MR at different concentrations, frequencies, and temperatures when used during various anaerobic and aerobic cycling tasks in hot environments ($\geq 30^\circ\text{C}$; Crosby et al., 2022; Flood et al., 2017; Gavel et al., 2021; Mündel & Jones, 2010; Tran Trong et al., 2015). Despite this, no investigation has provided a conservative or adjusted value for performance change at the individual level. In this study, individual improvement with MEN ranged from 0.3% to 5.1%, suggesting that MEN is not a "one-size-fits-all" model and that the individual utility of MEN needs to be considered.

While all athletes demonstrated a positive response to the use of MEN, only 64% (seven of 11) of the athletes were deemed "real" responders (performance improvement $>$ LSC%, threshold for typical variation). Of the seven "real" responders, four (57%) were classified as high responders ($>2.1\%$ change), two (29%) as moderate (1.0%–2.0% change), and one (14%) as minimal (0.1%–0.99% change), leaving four of the original 11 to be "nonresponders" (performance improvement $<$ LSC%; Gavel et al., 2023; Stevens & Best, 2017). As this is the first study to utilize an LSC% threshold in the interpretation of the effect of MEN on performance, it is believed that we are providing a more "true" interpretation of the ergogenic potential of MEN, softening our performance results albeit in a small sample population. In

light of this, it should be acknowledged that ~64% of the trained adolescent cyclists in this study significantly benefited from utilizing a repeated MEN MR during a high-intensity interval-based cycling test in the heat. Moreover, it is reasonable to assume that MEN's ergogenic effect may likely be lower than what has been reported in the literature, especially in trained athlete populations who are familiar with the demands of strenuous endurance tasks. Despite relatively small performance improvements with MEN, elite athletes benefit from marginal gains in performance, and MEN presents as a potential ergogenic strategy to help improve cycling power output during high-intensity events in hot environments.

Conclusions

The findings of this investigation suggest that repetitive oral rinsing of 0.01% MEN in the heat, increases power production during the latter stages of a 30-min race-like task for adolescent male cyclists. In this study, MEN augmented performance without causing further deterioration to perceptual states or inhibiting typical physiological responses, demonstrating its potential utility as a nonthermal ergogenic intervention in cycling events that take place in the heat.

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