**Title:** Menthol: A fresh ergogenic aid for athletic performance

**Running Head:** Menthol and athletic performance

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**Abstract**

The application of menthol has recently been researched as a performance enhancing aid for various aspects of athletic performance including endurance, speed, strength and joint range of motion. A range of application methods has been used including a mouth rinse, ingestion of a beverage containing menthol or external application to the skin or clothing via a gel or spray. The majority of research has focused on the use of menthol to impart a cooling sensation on athletes performing endurance exercise in the heat. In this situation, menthol appears to have the greatest beneficial effect on performance when applied internally. In contrast, the majority of investigations into the external application of menthol demonstrated no performance benefit. While studies are limited in number, menthol has not yet proven to be beneficial for speed or strength, and only effective at increasing joint range of motion following exercise that induced delayed onset muscle soreness. Internal application of menthol may provoke such performance enhancing effects via mechanisms related to its thermal, ventilatory, analgesic and arousing properties. Future research should focus on well-trained subjects and investigate the addition of menthol to nutritional sports products.

**Key Points**

- Menthol applied internally via a mouth rinse or a beverage containing menthol during endurance exercise in the heat is beneficial for performance
- Menthol is unlikely to have a beneficial effect on endurance exercise performance when applied externally to the skin via a gel or spray.
- Menthol has not yet proven to be beneficial for speed or strength, and only effective at increasing joint range of motion following exercise that induced delayed onset muscle soreness.

## 1. Introduction

The role of the brain in the regulation of exercise performance has received increasing attention across the last decade [1]. Opinion remains divided as to whether regulation occurs exclusively at the neurological level [2] or if interactions between various physiological and psychological feed-forward and feedback mechanisms to generate an athlete's feelings of self [3] and as such, fatigue whilst exercising [4]. What has been repeatedly demonstrated, however, is that physical performance can be modified through interventions acting exclusively on the central nervous system, for example, music [5] experimenter sex [6] and time or performance deception [7]. Various mouth rinsing techniques may also be performance enhancing, which involve briefly exposing the oral cavity to a stimulus (e.g. carbohydrate, caffeine, menthol) with the intention to induce afferent feedback to the brainstem that may ameliorate fatigue [8].

Carbohydrate mouth rinsing has been the main strategy studied to date, with it being postulated that the brief exposure of carbohydrate to the oral cavity elicits neurological responses associated with imminent nutrient availability [9], reward [10] and motor output [10]. These findings led to the emergence of other mouth rinsing strategies [8] including menthol [11]. A menthol mouth rinse is used to impart sensations of coolness, freshness and nasal patency through stimulation of the trigeminal nerve [12, 13] and as an agonist to the TRPM8 channel which serves as a cold temperature sensor [14]. These mechanisms and resultant sensations explain menthol's prolific use as a flavouring and fragrance agent in confectionary and medications [15].

Considering hotter perceptions of thermal sensation and discomfort negatively affect endurance exercise performance [16] and menthol has a perceptual cooling effect [12], it may be useful as an ergogenic aid for athletic performance, especially in hot environmental conditions [17]. Additionally, menthol has been proposed as a cooling and analgesic compound useful for application on injured and/or sore muscles, to promote recovery and enhance subsequent contraction force [18]. With a vast range of application methods, dosages, exercise protocols and performance outcomes however, the beneficial effect of menthol on athletic performance seems equivocal. Hence, the current review aims to provide recommendations for athletes using menthol to enhance athletic performance. The psychophysiological mechanisms of action will also be explored and directions will be provided for future research.

## 2. Literature Search Methods

Searching was carried out within the databases *PubMed* and *Scopus* up to October, 2016. Search terms included menthol, L-menthol, mint, peppermint, counterirritant, cooling, exercise, performance and thermal sensation. Inclusion criteria stipulated that investigations must be written in English and have implemented a menthol-based intervention on a measured aspect of athletic performance. Subjects of all abilities were included and while the majority of studies were performed in a hot environment (>30°C), investigations performed in neutral-warm environments (20-30°C) were also included.

## 3. Menthol and Athletic Performance

To date, the use of menthol as an ergogenic aid for athletic performance has taken the form of a mouth rinse [19], an additive to other beverages [20, 21] or as a gel or spray

applied externally to the skin or clothing [22, 23]. Hence, it is either applied internally or externally. Importantly, the degree of the cooling sensation from menthol to a body area correlates inversely with the thickness of the stratum corneum, where a thicker stratum corneum is a more difficult barrier to penetrate [24]. The density of cold-sensitive afferents on a particular body segment will also influence the degree of the cooling sensation from menthol application. Hence, for the same menthol dose, the tongue and oral cavity are more sensitive to menthol in comparison to the torso [24] and as such, the effects of menthol application on the oral cavity (internal) will be discussed separately to application on the skin (external).

### *3.1. Internal Application of Menthol and Athletic Performance*

A summary of research determining the effect of internal menthol application on physical capacity and performance appears in Table 1. A novel strategy is to simply rinse (or swill) the mouth with a liquid menthol solution prior to spitting out the solution. In the first study of its kind, a menthol mouth rinse (25 mL at a concentration of 0.01% performed every 10 min) significantly improved cycling time to exhaustion by 9% [11]. The researchers also observed significantly increased expired air volume, highlighting a greater drive to breath and/or lowered airway resistance, as well as a lower rating of perceived exertion. Similar findings have also been observed within running time trials in the heat, where menthol mouth rinse (25 mL at a concentration of 0.01% performed every 1 km) significantly improved 5 km performance time by 3% [19] and 3 km performance time by 3.5% when combined with a facial water spray [25]. Across these studies, significantly increased expired air volume was also observed alongside significantly cooler thermal sensation [19, 25]. Notably, the use of a menthol mouth rinse performed during exercise, whether

combined with facial water spray or not, was significantly more beneficial for running time trial performance in the heat compared to the use of well established pre-cooling strategies [19, 25]. As such, a menthol mouth rinse performed intermittently during exercise appears to be an effective intervention to improve endurance exercise performance in the heat.

**Insert Table 1 Here**

Two promising investigations on internal menthol application and endurance performance have involved ingesting a menthol-aromatized beverage [20, 21]. Riera et al. [20] performed several comparisons of different menthol-aromatized beverages that were ingested prior to and every 5 km during a 20 km cycling time trial in the heat. Menthol-aromatized beverages at 23°C, 3°C and ice slurry at -1°C were compared to a beverage of the same volume and temperature without menthol [20]. The addition of menthol to the 3°C beverage significantly improved performance time by 9%, while no significant differences were observed in the other conditions. Importantly, however, menthol-aromatized ice slurry was the most beneficial intervention compared to a 23°C control beverage without menthol. Similar studies out of the same laboratory have also demonstrated that the combination of menthol and ice slurry significantly improved performance in a simulated duathlon in hot conditions compared to other beverages also containing menthol at 28°C and 3°C, by 6% and 3%, respectively [21]. Hence, the addition of menthol to a beverage ingested immediately prior to and during endurance exercise has a performance enhancing effect, and like the menthol mouth rinse, this strategy is not further enhanced by pre-cooling [26]. For the best outcome, menthol should be added to an ice slurry mixture

to maximize cooling. Practically, however, recent research has demonstrated that when given the choice, athletes drink less ice slurry than cold fluid during a cycling time trial, which may contribute to deteriorated performance and feeling state [27].

Other investigations into menthol ingestion and sports performance have taken the form of peppermint ingestion, which typically contains a high concentration of menthol [28-30]. No performance improvements were gained in an outdoor 400 m running time trial following the ingestion of 5 $mL \cdot kg^{-1}$ of peppermint extract (50 g of dried mint infused into 1 L of water for 15 min) [28]. Hence, this initial study suggests menthol may not be an effective aid for such short duration activity, but more research is needed to confirm this notion. Other studies to investigate the use of peppermint ingestion as a pre-exercise ergogenic aid [29] or an oral supplement consumed every day for 10 days [30] were tarnished by failing to implement a cross-over design or failing to include a control trial, respectively.

### *3.2. External Application of Menthol and Athletic Performance*

A summary of research determining the effect of external menthol application on physical capacity and performance appears in Table 2. Half of these investigations have involved the spraying of a menthol solution onto the exercise clothing either prior to [31, 32] or during an endurance exercise time trial [22]. Spraying a menthol solution on the exercise clothing at a concentration of 0.05% resulted in no improvements in 40 km cycling time trial performance [31] or 5 km running time trial performance [32] despite significantly cooler thermal sensation and improved thermal comfort in both instances. The spray was also ineffective when the menthol solution was more concentrated (0.2%) and implemented at the 10 km mark of a 16.1 km

cycling time trial, despite lower ratings of perceived exertion, cooler thermal sensation and improved thermal comfort [22]. Only one study has demonstrated a beneficial performance effect of an external menthol application when a menthol gel at 8% concentration was applied to the face in a volume of 0.5 g·100 $cm^2$ [16]. This intervention increased total work completed by 21% in a cycling time to exhaustion protocol at a fixed rating of perceived exertion and was also accompanied by significantly cooler thermal sensation and improved comfort. As such, the external application of menthol may need to be applied directly to the face, or at least directly to the skin at a high concentration in order to have an ergogenic effect. It should be noted, however, that the perceptually driven protocol may be more likely to be affected by an intervention designed to influence perception and hence, further investigation into the application of menthol on the face is needed.

**Insert Table 2 Here**

Other investigations that have applied a menthol gel directly to the skin have assessed the effects on muscle strength [18, 33] and joint range of motion [34, 35]. A menthol gel applied to the forearm at a concentration of 3.5% and a volume of 0.5 g·100 $cm^2$ did not improve isokinetic muscle strength 20 minutes after application [33]. Similarly, a menthol gel with the same concentration and volume applied to the *biceps brachii* did not improve maximal voluntary contraction or evoked force of the elbow flexors 20 minutes after application and 48 hours after exercise that induced delayed onset muscle soreness [18]. In regards to joint range of motion, one investigation demonstrated that application of a 2% menthol gel increased range of motion of the elbow joint following an eccentric exercise protocol to induce delayed

onset muscle soreness [35], however, application of a 16% menthol gel did not affect hamstring range of motion in absence of preceding eccentric exercise [34]. Therefore, the use of a topical menthol gel appears to have little influence on muscle strength and joint range of motion in the recovered state.

## 4. Mechanisms of Action

The application of menthol for the improvement of endurance performance in the heat has been proposed to induce several psychophysiological adjustments including thermal [36], ventilatory [19], analgesic [18] and arousal effects [37].

### *4.1. Thermal Effect*

Improved feelings of thermal comfort and sensation are observed when menthol is applied topically [16, 22, 31, 32] and when administered orally [19, 25]. Researchers investigating topical application of menthol often apply garments that have been treated with low concentration menthol solutions. This facilitates evaporative cooling and stimulation of cold receptors by placing the garment and menthol in contact with large, cold sensitive areas such as the chest and back [38]. Specifically, the solvent (typically water and alcohol) evaporates as a result of an increased rate of heat production and skin temperature during exercise, whilst menthol stimulates cold sensitive TRPM8 receptors, creating a subjective feeling of coolness [12]. Menthol has, however, also been shown to promote a heat storage response during exercise [36, 39] and at rest [40] due to perturbed sweat rate [23] and vasoconstriction of blood vessels [40, 41]. These thermoregulatory responses may explain why topical application of menthol is not beneficial for endurance performance in the heat when applied to large areas, prior to or during an intense and prolonged bout of exercise

[40]. When menthol is applied to smaller areas, such as the face, these physiological responses are not observed, yet cooler thermal sensation and improved thermal comfort still occur [16]. However, the disassociation between the physiological and perceptual responses to body heat from topical menthol application presents an ethical consideration for researchers, as it may permit exercise beyond normal thermal limits and an increase in the stress hormone prolactin [19]. Application of menthol close to the onset of hyperthermia should be avoided to allow perception of symptoms associated with high levels of heat stress, adjustment to self-selected exercise intensity and the prevention of heat injury.

When administered orally, menthol evokes pleasant and refreshing sensations of airflow and nasal patency, improving thermal comfort and sensation by acting as an afferent to the palatine and trigeminal nerves [13, 15]. Despite performance improvements with oral menthol supplementation when used in conjunction with other cooling methods, thermal perception was not cooler in protocols performed outside of the laboratory [20, 21]. Such a finding suggests that in the presence of airflow, oral application of menthol improves performance by mechanisms beyond improvements in thermal perception.

*4.2. Ventilatory Effect*

Menthol consistently increases ventilation in the form of expired air volume [11, 19, 25] when administered as a liquid mouth rinse (0.01%) with concomitant improvements in running performance [19, 25] and cycling time to exhaustion [11]. While at rest, oral application of menthol inhibits the drive to breathe [12] and deceases the discomfort experienced during breathing with a restrictive load [42],

serving to reduce ventilation [43]. Therefore, since exercise increases the ventilatory requirements of the body, at times to a near maximal level [44], oral administration of menthol during exercise can lower perceived cardiopulmonary exertion [11] which may allow an overall greater depth and/or rate of breathing. However, there is no evidence that menthol has the capacity to decrease physical airway resistance [13, 45, 46], suggesting the effect is perceptual only [42, 45].

### *4.3. Analgesic Effect*

Menthol has been used for medicinal purposes since ancient times [14] and more recently, it has been suggested to have an analgesic effect for sports injuries, delayed onset muscle soreness and arthritis [15, 18] and hence its inclusion in many topical creams to reduce musculoskeletal pain. Aside from its cooling effect through the TRPM8 channel, menthol has been demonstrated to inhibit the TRPA1 channel, a mediator of inflammatory pain [47]. While topical application of menthol (3.5%) decreased perceived pain and improved physical function in patients with knee osteoarthritis [48], research to date has not investigated the analgesic effects of menthol during exercise in athletes.

### *4.4. Arousal Effect*

Menthol has also been suggested to have arousing properties similar to the feeling of cold air on the face when drowsy [12]. Chewing menthol gum has been associated with improved mental alertness [37] and breathing a menthol fragrance through a mask increased vigilance in a sustained visual attention task [49]. In contrast however, chewing on a menthol lozenge failed to enhance mood ratings of alertness, hedonic tone and tension during simulated firefighting in the heat [50]. As such,

further research is needed to determine if arousal plays a role in the improvement of endurance exercise performance in the heat from internal menthol application.

## 5. Practical Recommendations

Endurance athletes competing in the heat are recommended to experiment with internal menthol application methods both pre-and mid-exercise. This may take the form of a mouth rinse or a beverage containing menthol by adding 0.1-0.5 g of crushed menthol crystals, dissolved in alcohol, to 1 L of water. Alternatively, a pre-mixed L-menthol/alcohol solution that is available commercially as a food additive can be used in the same quantity. Athletes should experiment with different concentrations of menthol in their beverages to find individual limits that are both tolerable and beneficial to performance. Indeed, all attempts at internal menthol application should be trialled thoroughly within mock competition scenarios at race intensities to ensure no adverse consequences are to occur in a race situation.

## 6. Directions for Future Research

To improve translation for athletes, future research into menthol and sports performance should recruit well-trained subjects. Only half of the investigations presented in Tables 1-2 used trained or well-trained subjects, which is known to improve test reliability [51] and is also important to understand the specific responses within this population. It should be noted that for the studies concerning the internal application of menthol and endurance performance, the researchers formulated their own liquid menthol solution for mouth rinsing or ingestion. Hence, development of an optimal solution for these purposes is needed, and further, experimentation with combinations of menthol, carbohydrate, electrolyte and caffeine would increase

practicality for athletes. Synthetic compounds with similar cooling effects should also be considered as they may have improved palatability and may be easier to formulate [24]. Future researchers should ensure that the dose of any external solution is specified (in $g \cdot cm^2$) to simplify comparisons between studies and further, assessment of the dose-response relationship is also needed for the various menthol application methods. Finally, current research has focussed on the thermal and ventilatory mechanisms of internal menthol application, while the analgesic and arousing properties of menthol may also contribute to improved endurance exercise performance in the heat. Hence, these measures should be incorporated into future research.

## 7. Conclusion

The majority of research has focused on the use of menthol to impart a cooling sensation on athletes performing endurance exercise in the heat. In this situation, menthol appears to have the greatest beneficial effect on performance when applied internally. Conversely, only one study observed an improvement in endurance exercise capacity following external application of menthol. While studies are limited in number, menthol has not yet proven to be beneficial for speed or strength and only effective at increasing joint range of motion following exercise that induced delayed onset muscle soreness. Internal application of menthol likely stimulates improvements in endurance performance in the heat through thermal and ventilatory mechanisms, however the analgesic and arousing properties of menthol may also play a role.

## Compliance with Ethical Standards

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*Conflicts of Interest*

Christopher Stevens and Russell Best declare that they have no conflicts of interest relevant to the content of this review.

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**Table 1.** Summary of research determining the effect of internal menthol application on physical capacity and performance.

| Investigation | Ambient Conditions | Subjects | Menthol Application Method | Protocol | Outcome |
|---|---|---|---|---|---|
| Mundel and Jones [11] | 34°C, 27% RH | 9 males, $VO_2max$ = 54 ± 5 mL·kg$^{-1}$·min$^{-1}$ | Menthol mouth rinse (25 mL at 0.01% every 10 min) | Cycling TTE at 65% $VO_2max$ | ↑ TTE by 5 min (9%)<br>↑ VE, ↓ RPE |
| Sönmez et al. [28] | NR | 16 (sex NR), untrained | Oral mint extract (5 mL·kg) ingested prior to performance test | Running TT of 400 m | ↔ Perf time<br>↓ BLa, ↔ muscle pain |
| Riera et al. [20] | 31°C, 78% RH | 12 males, $VO_2max$ = 60 ± 10 mL·kg$^{-1}$·min$^{-1}$ | Ingestion of beverage with/without menthol (190 mL at 0.05% 3 x prior and every 5 km during exercise) at a) 23°C; b) 3°C; or c) -1°C ice slurry | 15 min cycle at ventilatory threshold one then 20 km TT | a) ↔ Perf time<br>b) ↑ Perf time by 3 min (9%)<br>c) ↔ Perf time<br>↔ HR, RPE, TC or TS |
| Tran Trong et al. [21] | 28°C, 57% RH | 10 males, $VO_2max$ = 59 ± 11 mL·kg$^{-1}$·min$^{-1}$ | Ingestion of a menthol aromatized beverage (190 mL at 0.05% during WU, every interval and recovery) at a) 3°C; or b) 0.2°C ice slurry, compared to 28°C fluid | 15 min cycle WU then 5 x intervals of (4 km cycle and 1 km running TT) | a) ↔ Perf time<br>b) ↓ Perf time by 5 min (6%) and ↓ perf time by 2 min (3%) compared to 'a'<br>↔ HR, RPE, TC or TS |
| Stevens et al. [19] | 33°C, 46% RH | 11 males, 5 km run time of 18-22 min | Menthol mouth rinse (25 mL at 0.01% every 1 km) | 10 min walk/run on NMT then running TT of 5 km on NMT | ↓ Perf time by 0.7 min (3%)<br>↓ TS, ↑ VE, ↑ PRL, ↔ SR |
| Stevens et al. [25] | 33°C, 47% RH | 11 males, $VO_2max$ = 61 ± 6 mL·kg$^{-1}$·min$^{-1}$ | Menthol mouth rinse (25 mL at 0.01% every 4 min/1 km) and facial water spray (every 4 min/1 km) | 20 min run at 70% $VO_2max$ on NMT then running TT of 3 km on NMT | ↓ Perf time by 0.5 min (3.5%)<br>↓ TS, ↓ $T_F$, ↓ PRL, ↑ VE, ↔ SR |
| Riera et al. [26] | WBGT: 29°C, 80% RH | 9 males, $VO_2max$ = 59 ± 11 mL·kg$^{-1}$·min$^{-1}$ | Ingestion of menthol aromatized ice slurry during exercise (7 mL·kg at 0.03%) with vs. without pre-cooling with cold water (7 mL·kg at 3°C) | 10 min cycle at ventilatory threshold one then 30 km time trial | ↔ Perf time<br>↔ TS, TC, HR, RPE, $T_{CORE}$ |

↔ = no change, BLa = blood lactate concentration, HR = heart rate, NMT = non-motorized treadmill, NR = not reported, perf = performance, PRL = blood prolactin concentration, RH = relative humidity, RPE = rating of perceived exertion, SR = sweat rate, TC = thermal comfort, $T_{CORE}$ = core temperature, $T_F$ = forehead temperature, TS = thermal sensation, TT = time-trial, TTE = time to exhaustion, VE = volume of expired air, $VO_2max$ = maximal oxygen uptake, WBGT = wet blub globe temperature, WU = warm-up.

**Table 2.** Summary of research determining the effect of external menthol application on physical capacity and performance.

| Investigation | Ambient Conditions | Subjects | Menthol Application Method | Protocol | Outcome |
|---|---|---|---|---|---|
| Schlader et al. [16] | 20°C, 48% RH | 12 males, untrained | Topical application of menthol gel on the face (0.5 g·100 $cm^2$ at 8% prior to protocol) | Cycling TTE RPE clamp protocol at 16 *'hard-very hard'* | ↑ Total work by 39 kJ (21%)<br>↓ TS, ↑ TC |
| Topp et al. [33] | NR | 9 males, 8 females, untrained | Topical application of menthol gel on the right forearm (3.5 g total: 0.5 g·100 $cm^2$ at 3.5% 20 min prior to protocol) | 30 repeated maximal flexions and extensions of the wrists at 30°·s | ↔ Muscle strength<br>↓ Blood flow in radial artery |
| Johar et al. [18] | NR | 12 males, 4 females, untrained | Topical application of menthol gel on the *Biceps Brachii* (2 g total: 0.5 g·100 $cm^2$ at 3.5% 20 min prior to protocol) | MVC and EF of the elbow flexors 48 h post DOMS inducing exercise | ↔ MVC or EF<br>↓ Perception of DOMS |
| Barwood et al. [31] | 32°C, 50% RH | 11 males, 40 km cycle time < 70 min | Menthol sprayed on the cycling jersey (106 mL at 0.05% between WU and TT) | Cycling TT of 40 km | ↔ Perf time<br>↓ TS, ↑ TC |
| Barwood et al. [32] | 34°C, 50% RH | 6 males, untrained | Menthol sprayed on the running top (100 mL at 0.05% between pre-load and TT) | 15 min fixed intensity pre-load run then 5 km TT | ↔ Perf time<br>↓ TS, ↑ TC |
| Barwood et al. [22] | 34°C, 33% RH | 8 males, untrained | Menthol sprayed on the cycling jersey (100 mL at 0.2% after 10 km of TT) | Cycling TT of 16.1 km | ↔ Perf time<br>↓ RPE, ↓ TS, ↑ TC |

↔ = no change, DOMS = delayed onset muscle soreness, EF = evoked force, NR = not reported, MVC = maximal voluntary contraction, perf = performance, RH = relative humidity, RPE = rating of perceived exertion, TC = thermal comfort, TS = thermal sensation, TT = time-trial, TTE = time to exhaustion, WU = warm-up.